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Special Report No. 18
April 1989

# WATER SUPPLY ISSUES IN THE METROPOLITAN TWIN CITIES AREA: PLANNING FOR FUTURE DROUGHTS AND POPULATION GROWTH

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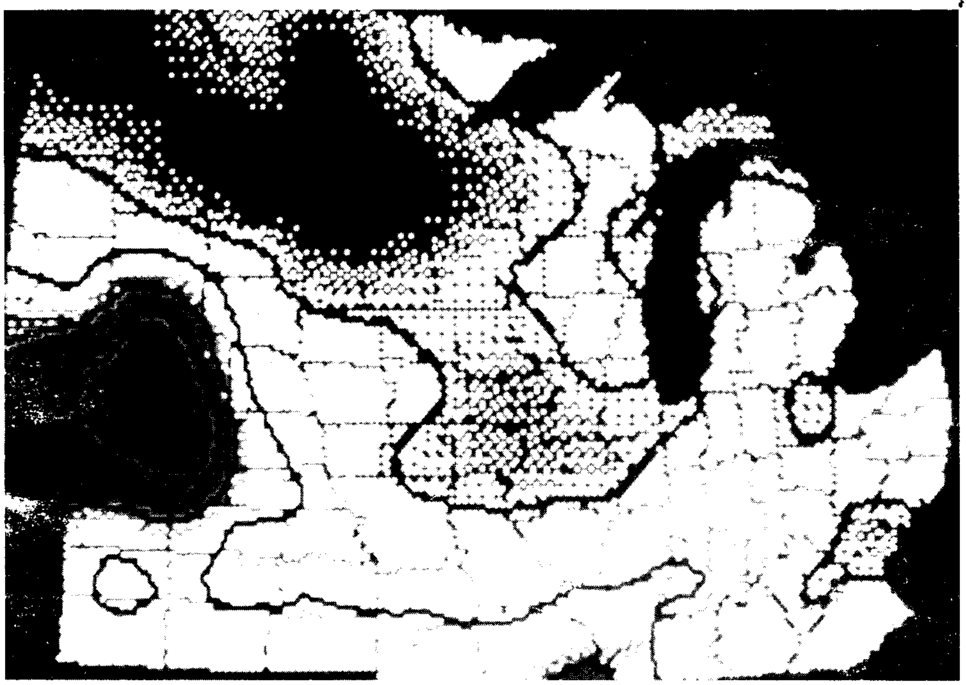
Summary of a Workshop
October 25, 1988



wrrc minnesota water resources research center

# WATER SUPPLY ISSUES IN THE METROPOLITAN TWIN CITIES AREA: PLANNING FOR FUTURE DROUGHTS AND POPULATION GROWTH

## Summary of a Workshop
## October 25, 1988

**Patrick L. Brezonik, Editor**

| | |
|---|---|
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## Acknowledgements

The technical program for the workshop on metropolitan water supply issues was planned by the committee listed at the bottom of this page. Special thanks are extended to the panel chairs for helping to organize the topics of their panels, preparing the issue statements, and arranging panel membership. The cooperation of Jack Ditmore, Chair of the Metropolitan Water Supply Task Force, and all members of the task force in planning and participating in the workshop is gratefully acknowledged. Editorial assistance in preparing the proceedings was provided by Liz Espointour and Alice Tibbetts. Support for the workshop and publication of the proceedings was provided by the Water Resources Research Center through the University of Minnesota Graduate School.

## Workshop Planning Committee

Patrick Brezonik, Water Resources Research Center, Univ. of Minnesota, chair
Dwight Brown, Dept. of Geography, Univ. of Minnesota
Gary Englund, Minnesota Dept. of Health
Kent Lokkesmoe, Dept. of Natural Resources
Gary Oberts, Metropolitan Council
Bruce Olsen, Minnesota geological Survey
Heinz Stefan, Dept. Civil & Mineral Engrg., Univ. of Minnesota

## Workshop Overview

The severe drought of 1988 focused attention on water supply concerns in the metropolitan Twin Cities area. During the height of the drought, flow rates in the Mississippi River dwindled to critically low values, and increased demand caused large declines in water levels of supply wells throughout the area. The experience of the summer of 1988 demonstrated that regional water supply and water use problems during drought are potentially serious. In addition, they are highly complicated because of:(1) the many competing interests and demands, (2) the numerous agencies involved in water management, (3) the diversity of water sources used in the metropolitan area, (4) the interactions among water quality, water use, and water supply, and (5) the fact that surface water used in the metropolitan area originates in a nonmetropolitan area (the Mississippi River Headwaters Region), which has its own priorities and perspectives for water use.

Real and potential supply problems identified during the drought led to the formation of the Metro Water Supply Task Force by Minnesota Governor Rudy Perpich. The Task Force was charged with examining water supply needs for the metro area and recommending a course of action to reduce its dependency on the Mississippi River as a water source, while continuing to assure an adequate supply for the region. The workshop summarized in this publication was held at the University of Minnesota in St. Paul on October 25, 1988 as an activity of the task force. The workshop had four objectives:

(1) *gather facts on physical and legal aspects of the topic: magnitude of regional water resources, present and projected water demands, changes in water availability that would occur with possible climate changes, and status of water law and regulations affecting potential solutions;*
(2) *refine the issues that the Task Force was to address;*
(3) *seek public input regarding these issues; and*
(4) *examine options to address the issues and solve these problems.*

Six panels addressed these issues at the workshop in the following order: (1) surface and groundwater resources of the region; (2) climate trends and regional precipitation patterns; (3) water use patterns in the metro area; (4) water uses and user interests in the Mississippi Headwaters region; (5) legal issues concerning water transfers and regulation of Headwaters reservoirs; and (6) alternative water supply possibilities for the metro area. Panel members were selected based on technical expertise and experience with regional water supply problems, and to represent the array of water users, management agencies, and concerned interest groups. Panel chairs prepared a list of issues they considered to be most relevant to the topic of their panel. These were circulated to panel members and formed the basis of the panel presentations and discussions. The issue statements were modified in response to comments and discussion during the workshop. The issue statements form the framework for the workshop proceedings. Summary papers prepared by panel members expanded on one or more of the issues. Both the issues statements and summary papers were edited for continuity and style for this proceedings. It is hoped that the information presented in this report will lead readers to a greater under-standing of three aspects of the subject:

(1) *what actually happened concerning the area's water resources and water demands during the drought of 1988;*
(2) *the physical alternatives available to expand the area's water resources and mitigate effects of future droughts; and*
(3) *the legal, institutional, social and economic constraints both on present management strategies and on adoption of alternative water supply strategies.*

## Panel I: SURFACE AND GROUNDWATER HYDROLOGY OF THE REGION

**CHAIR: BRUCE OLSEN**
Minnesota Geological Survey, St. Paul, MN

The purpose of this panel was to summarize information about the availability of water in the metropolitan Minneapolis-St. Paul area. Based on recent and ongoing hydrologic studies, the region's groundwater resources were characterized in terms of geographic extent and magnitude of the major supply aquifers, rates of recharge, and trends in aquifer drawdown. Surface water resources available to the metropolitan area were summarized, with special attention paid to the hydrology of the Mississippi River and to the history and functions of the headwaters reservoir system. Specific issues and topics discussed by the panel included:

(1) overview of the area's surface water and groundwater resources;
(2) history of the Mississippi headwaters reservoir system;
(3) decrease in streamflow during summer 1988 and reasons for concern;
(4) overview of surface water conflicts;
(5) concerns over the quality and quantity of groundwater resources; and
(6) information needs to better understand the dynamics of the area's groundwater resources

### Regional groundwater hydrology for the Twin City metropolitan area
Bruce Olsen, Geologist, Minnesota Geological Survey, St. Paul, MN

Most of the seven-county twin city metropolitan area's water needs are supplied from groundwater. The exception is the urban core area where surface water is used by Minneapolis and St. Paul. Bedrock aquifers composed of sandstone and carbonate rocks are hydrologically separated by confining layers of siltstone and shale. The layer-cake arrangement of bedrock aquifers is gently warped into a northeast trending depression termed the Twin City artesian basin. The entire region has been glaciated repeatedly, and the thickness of glacial sediments exceeds 500 feet in some places. Extensive outwash and terrace deposits or buried sand and gravel units also serve as aquifers. Generally, glacial aquifers are important sources of groundwater on a local basis but do not exhibit uniform hydrogeologic characteristics throughout the area. Their use by high capacity wells is limited. The sequence of the bedrock aquifer systems and their water use characteristics are summarized in Table 1.

The groundwater resources of the Twin Cities area are finite and are subject to contamination. Only two aquifer systems, the Mt. Simon-Hinckley and Prairie du Chien-Jordan, yield more than 500 gallons per minute to sustained pumping. Together they supply about 80 percent of the groundwater used in the area.

The Mt. Simon-Hinckley aquifer underlies this entire area, but it is stratigraphically lowest and little is known about its hydrogeology. Residence studies using isotopes of carbon and hydrogen show that ages of Mt. Simon-Hinckley water pumped from outlying margins of the Twin Cities artesian basin are a few thousand years old, while water pumped from the center is tens of thousands of years old.

The pattern of increasing age indicates that much of the recharge to the Mt. Simon-Hinckley aquifer comes from outside the seven-county Twin Cities area and that natural rates of recharge probably are very slow. The hydrologic separation of this aquifer from overlying groundwater aquifer is evidenced by the dramatic and widespread fluctuation in head caused by seasonal pumping of high capacity wells. Data collected by the USGS and Minnesota DNR show a 200-foot head loss due to pumping since the turn of the century.

The Prairie du Chien-Jordan aquifer is present over only about half of the Twin Cities area. It is probably sensitive to surface contamination in a significant part of the area where it exists (Figure 1). It is the most heavily pumped aquifer in the area, and most high capacity wells utilize it. Shifting population centers and water use from the urban core to the suburbs have caused a corresponding shift in pumping centers. Water levels in the aquifer appear to have stabilized relative to pumping stress, although a head loss of about 90 feet has occurred since the turn of the century, according to USGS and Minnesota DNR data. Detailed monitoring data on the effects of seasonal pumping are not available to evaluate whether pumping will cause the degradation of water quality, especially in geologically sensitive areas. Land use practices, particularly waste disposal, already have contaminated parts of this aquifer.

Two major concerns have been expressed regarding the long-term management of the area's groundwater resources:

1) the use of well fields that concentrate the effects of high capacity pumping; and
2) improperly constructed and abandoned wells that may funnel surface contamination into the aquifer.

Concentrating municipal or other high capacity wells in clusters is attractive from an engineering and economic viewpoint, because the costs of treating and delivering water can be limited to a central facility. However, well fields create localized cones of depression that may become severe during periods of heavy water use in the summer. Closely spaced wells interface with each other, reducing their efficiency and increasing the danger of drawing surface contamination into the well field. Also, pumping interference between two or more community well fields may limit future pumping capacities between these and surrounding communities. Additional water supplies required by expanding suburban communities may not be available if planning for proper well placement is not implemented today.

Tens of thousands of water wells were constructed in the seven county Twin Cities area before the state water well code went into effect in the mid 1970s. Wells that interconnect aquifers, that are constructed of substandard materials or without consideration of sanitation spread surface contamination into the groundwater resources.

Abandoned wells also may spread pollution. Sealing large-diameter wells in certain geologic settings can be extremely expensive, nonetheless, abandoning wells to prevent contamination must receive the same amount of regulation as construction of new wells.

Table 1. Bedrock Aquifer Systems of the Seven-County Twin City Area

| Geologic Unit (average thickness in feet) | Hydrogeologic Properties | Water Use |
|---|---|---|
| Decorah shale (40)<br>Platteville limestone (30)<br>Glenwood shale (5) | regional confining layer | locally, Platteville supplies domestic wells |
| St. Peter sandstone (160) | aquifer with confining layers in lower half | chiefly supplies domestic wells |
| Prairie du Chien dolomite (150)<br>Jordan sandstone (90) | aquifer | high-capacity wells; many domestic wells |
| St. Lawrence siltstone (50) | regional confining layer | domestic use locally |
| Franconia sandstone (140)<br>Ironton sandstone (25)<br>Galesville sandstone (35) | aquifer | domestic and localized high-capacity use |
| Eau Claire shale (80) | regional confining layer | very localized use by domestic wells |
| Mt. Simon sandstone (175)<br>Hinckley sandstone (10) | aquifer | high-capacity and very localized domestic use |
| Older bedrock undivided | generally non-aquifers | non used |

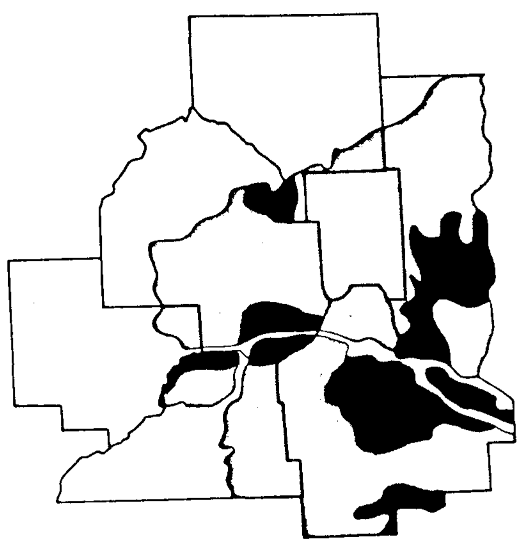

Figure 1. Distribution of the Prairie du Chien-Jordan aquifer in the Seven-County Twin City Metropolitan Area. Darker areas are geologically sensitive parts of the aquifer.

Planning for future water uses in the Twin Cities area should be a continuing process, not a reaction to drought or to local concerns over groundwater quantity and quality. Implementing any plan must be based on a greater understanding of groundwater resources than is currently available. Detailed monitoring is needed to determine the effects of seasonal versus long-term pumping at the municipal level. Protecting groundwater quality will involve much tighter controls over land use and well abandonment than currently exists. The area's groundwater resources are by definition out of sight, but they must not be out of mind if the goal of adequate water supply is to be met.

**Preliminary Evaluation of Effects of Groundwater Withdrawals on Mississippi River Flow Near the Twin Cities Metropolitan Area, Minnesota**

Jeffrey D. Stoner and Michael E. Schoenberg, Hydrologists, U.S. Geological Survey, St. Paul, MN

The drought of 1987-88 has fostered interest in the factors that affect water supply in the Twin Cities metropolitan area. A review of previous hydrologic investigations and data indicates that the flow of the Mississippi River could be affected by groundwater withdrawals. Flow in the upper Mississippi River is maintained by groundwater seepage during periods of little or no precipitation. Highly permeable sand and gravel aquifers in glacial drift are the principal sources of groundwater from the river's headwaters to Minneapolis. Base flow is supplemented further by discharge from sedimentary rocks that lie under the metropolitan area.

Continuous recording streamflow gages, operated for 40-100 years, provide records that help define low flow characteristics of the river. The 7 day, 10 year low flow for the Mississippi River near Anoka is 1,180 cfs (cubic feet per second). In St. Paul, below the mouth of the Minnesota River, it is 1,430 cfs. These low flow statistics are based on daily mean streamflow records from 1931-83 and from 1892-1983, respectively. Both records include effects of the severe drought of the 1930s and releases from headwater dams required to provide water for river navigation prior to the construction of locks and dams on the Mississippi River below the Twin Cities. The lowest recorded daily mean flow, unaffected by stream regulation for the Mississippi River, was 603 cfs near Anoka and 632 cfs at St. Paul in 1934. Because the aquifers respond relatively slowly to a drought, flow in the river was sustained by groundwater seepage even during the prolonged drought of the 1930s, (which had a probable recurrence interval of 100 years).

Groundwater withdrawals from bedrock aquifers beneath the Twin Cities metropolitan area intercept groundwater seepage to the Mississippi River. The aquifer system consists of four bedrock aquifers separated by confining layers of relatively low permeability and by the overlying glacial drift. About 80 percent of groundwater withdrawn in the metropolitan area is from the Prairie du Chien-Jordan aquifer (in the Ordovician Prairie du Chien Group and the Cambrian Jordan Sandstone), a highly fractured dolomite and sandstone in the upper part of the bedrock sequence. Most of the remaining groundwater withdrawals are from the lowermost confined bedrock aquifer, Mount Simon-Hinckley (in the Cambrian Mount Simon Sandstone and Precambrian Hinckley Sandstone), and sand and gravel aquifers in glacial drift.

From the perspective of a steady state water balance, groundwater discharge (base flow) to streams theoretically is equal to aquifer recharge less groundwater withdrawal. On the basis of empirical estimates of available recharge (about 6 inches per year) over a 3,500-square-mile area of the Twin Cities metropolitan area, the probable maximum sustained yield of the Prairie du Chien-Jordan and Mount Simon-Hinckley aquifers is about 1,700 cfs. A revised estimate of sustained yield from these aquifers is about 1,000 cfs, according to results of simulations based on a three dimensional model of groundwater flow in the entire aquifer system. The lower estimate is based on an improved definition of average recharge and actual or probable locations of pumped wells, which do not necessarily yield water at optimum rates of withdrawal from the aquifer system. By the same model, a streamflow depletion of 150 cfs was estimated for the Mississippi River through the metropolitan area in a simulation that represented a groundwater withdrawal of about 790 cfs (510 million gallons per day) projected for the year 2000. For a simulation representing a severe drought in 2000 (withdrawal of about 1,000 cfs), a streamflow depletion of 225 cfs was estimated.

The accuracy of these results is limited by poorly understood factors such as the time dependent dynamics of net aquifer recharge through the glacial drift aquifer, storage in confining layers, and groundwater leakage through streambed and valley fill sediments beneath the Mississippi River. A steady state condition of flow is assumed in these model projections, but an increase in average recharge of 1.4 inches per year to the bedrock aquifers might be possible under nonequilibrium conditions by short-term release of water from the glacial drift. Therefore, results of the model simulations appear to be reasonable for predicting the effects of short-term drought. However, they underestimate streamflow interception for a long-term drought. These data and studies show that base flow in the Mississippi River in the Twin Cities metropolitan area is sensitive to groundwater withdrawals during a drought, but the precise affect cannot be quantified without further study.

Follow-up studies currently are being conducted to improve information on the hydraulic connection between bedrock aquifers, valley sediments, and major rivers in the metropolitan area. Studies are being considered to evaluate the dynamics of aquifer recharge as related to groundwater withdrawals. The scenarios for groundwater development in the area assume that water quality in the Prairie du Chien-Jordan aquifer is suitable for human consumption and most other uses. However, case histories show that contamination by hydrocarbon compounds has made some parts of this aquifer non-potable. Further studies are needed on susceptibility of this aquifer to contamination from land surface activities.

## Mississippi Headwaters Reservoirs: Physical Characteristics and History

Ron Nargang, Minnesota Department of Natural Resources, St. Paul, MN

The current drought has stirred debate about the release of water from the Mississippi River headwaters reservoirs. Unfortunately, their original purpose of flood control and flow augmentation during a drought does not mesh well with their current uses for recreation. This paper describes the physical characteristics of the reservoirs and presents a brief historical summary of their uses.

Authorized by Congress in 1880, three of six headwaters reservoirs were placed in operation in 1884 (see Figure 2 for locations and Table 2 for physical characteristics of the reservoirs). Winnibigoshish (Winni) provides the greatest storage capacity through significant increases in both lake area and water levels (compared with the original [undammed] lake). Leech also provides significant storage because of its great size, though damming resulted in a more modest water level increase. Pokegama, near Grand Rapids, provides substantially less storage and functions as a reregulating reservoir. It takes about 13 days travel time for water to flow downstream to Pokegama from Winni and Leech because of marshy flow conditions. Water from Pokegama then takes about 10 days to reach the Twin Cities.

Big Sandy Reservoir was completed next in 1895. It has the next-to-smallest storage capacity and a relatively small natural basin, The reservoir was constructed to provide flood protection to the City of Aitkin. The Pine Reservoir (Whitefish Lake Chain), upstream from Brainerd, was completed in 1886 and provides the third largest storage capacity. Gull Lake Reservoir, northwest of Brainerd, which has the smallest capacity, was completed in 1912.

Figure 2. Mississippi River Headwaters Reservoirs

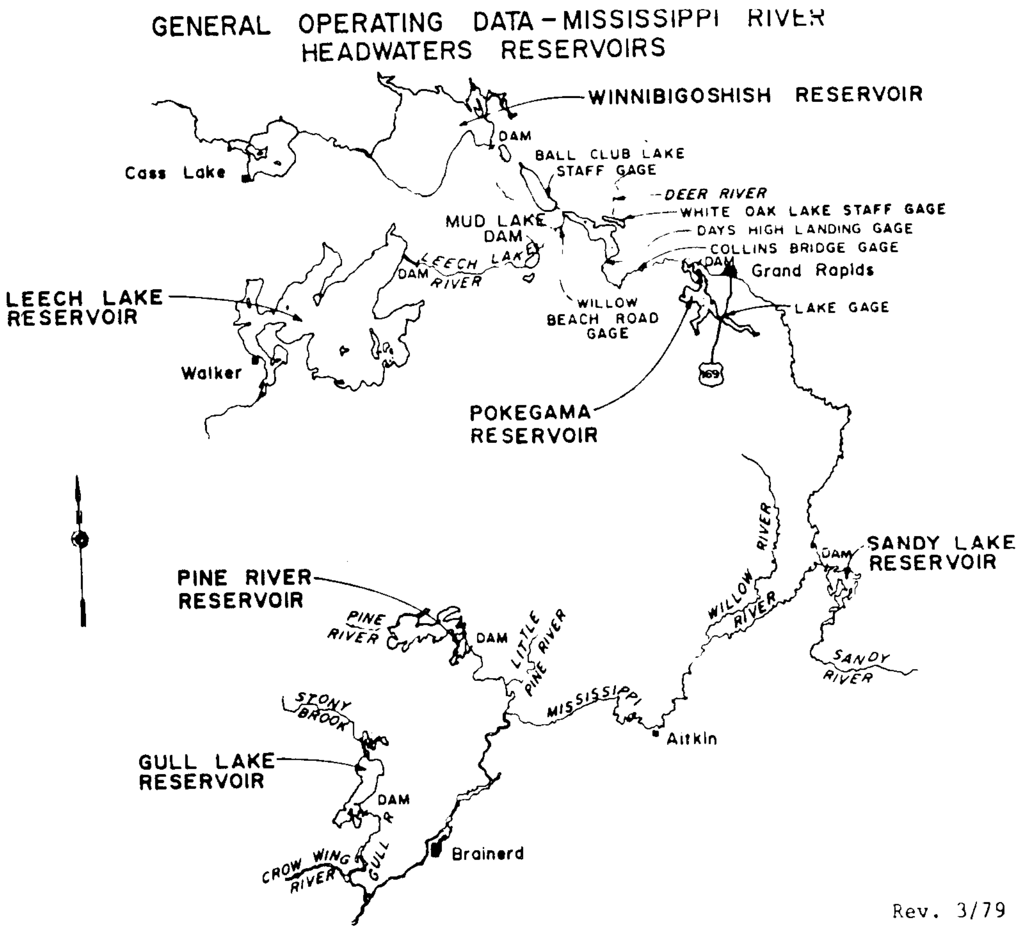


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Table 2. General Operating Data - Mississippi River Headwaters Reservoirs

Lake Elevations in Feet - 1929 ADJ.

| Reservoir | Winnibigoshish | Leech | Pokegama | Sandy | Pine | Gull |
|---|---|---|---|---|---|---|
| Normal spring stage (Date) | 1296.94(3/1) | 1293.20(3/1) | 1270.42(3/15) | 1214.31(2/15) | 1227.32(2/15) | 1192.75(2/15) |
| Desirable summer range | 1298.94-<br>1299,44 | 1294.50-<br>1294.90 | 1273.17-<br>1273.67 | 1216.06-<br>1216.56 | 1229.07-<br>1229.57 | 1193.75-<br>1194.00 |
| Original operating limits | 1288.94-<br>1303.14 | 1292.20-<br>1297.94 | 1268.92-<br>1276.42 | 1207.91-<br>1218.31 | 1217.62-<br>1234.82 | 1188.75-<br>1194.75 |
| Capacity, original operating limits, AD-FT | 982,600 | 742,500 | 97,500 | 78,600 | 177,900 | 71,600 |
| Present operating limits | 1294.94-<br>1303.14 | 1292.70-<br>1297.94 | 1270.42-<br>1276.42 | 1214.31-<br>1218.31 | 1225.32-<br>1231.32 | 1192.75-<br>1194.75 |
| Capacity, present operating limits, CA-FT | 668,800 | 689,000 | 80,100 | 37,600 | 79,900 | 26,000 |
| Flowage rights acquired to elevation of | 1306.94+ | 1301.70+ | 1280.42+ | 1222.31+ | 1238.82+ | 1198.75+ |
| Maximum elevation ever attained | 1303.39 | 1297.88 | 1277.92 | 1224.82 | 1234.56 | 1195.05 |
| Number of times upper operating limit has been exceeded | 2 | 0 | 18 | 18 | 0 | 8 |
| Number of times flowage limits have been exceeded | 0 | 0 | 0 | 1 | 0 | 0 |

Headwaters Reservoir Facts

* Congressionally Authorized 1880 Completed 1884-1912
* Six Reservoirs Utilized Natural Lake Basins
* Water Levels Raised 2.5 ft. to 11.5 ft. (est).
* Flowage easements retained or acquired by federal government.
* Original storage capacity 2.2 million acre feet of water.
* Operated primarily for recreation, flood control and habitat (50 yrs).
* Desirable operating limits markedly reduce but don't eliminate usable storage.

Leech Lake Reservoir (Completed 1884)
* Largest in area, modest water level increase
* Greatest reservoir capacity under current limits.

Winnibigoshish Reservoir (Completed 1884)
* Water levels raised substantially, continuing bank erosion problems.
* Greatest reservoir capacity under original operating limits, now second.

Pokegama Lake Reservoir (Completed 1884)
* Modest lake level increase, smaller reservoir capacity.
* 13 days travel time below Leech and Winni (marshy conditions).
* 10 days travel time to Twin Cities.

Big Sandy Reservoir (Completed 1895)
* Substantial water level increase, but small reservoir capacity.
* With the three foregoing reservoirs, has provided flood control (Aitkin vic.).

Pine River Reservoir (completed 1886)
* Significant water level raise effecting 11 lakes.
* Original reservoir capacity severely restricted by development.

Gull Lake Reservoir (Completed 1912)
* Modest water level raise, smallest reservoir capacity.
* Severely restricted by recreational development.

Between 1931 and 1936, the operation of the reservoirs was modified to augment streamflow at the Twin Cities during the summer months. Over the years, the need for nagivational water supply decreased (as lock and dam structures were installed downstream in the river),and the importance of recreation and tourism to the local economy has increased.

The Minnesota Legislature scrutinized the headwaters lake management situation between 1957 and 1961. The result was the enactment of portions of Minnesota Statutes, Chapter 110, concerning joint federal state control and a plan for operation of the dams. An operating plan was developed and adopted through a series of public hearings in 1962. Although never formally adopted by the federal government, the plan has guided reservoir operation. It provides for management of the system to protect and enhance recreational values of the reservoirs, reduce downstream flood damages and supplement stream flow during low flow periods.

Controversy over operation of the Headwaters Reservoirs should not be surprising when we consider the variety and importance of uses dependent on their management. These include: 1) intensive recreation/tourism development on the six main reservoirs as well as dozens of smaller waters linked by connecting channels; 2) propagation of fish and wildlife; 3) power production including hydropower and coal, and nuclear generation; 4) municipal water supply; 5) flood control; 6) tribal interests with rice production and other interests of Native Americans (hunting and fishing); 7) industrial/commercial water use; and 8) agricultural irrigation.

It is convenient to divide the history of the reservoirs into four time frames.

1880-1931 This period covers the construction and early operation of the reservoir system. Navigation and rafting of timber represent the major demands. The period is characterized by low population densities in the Headwaters region, little recreation development and a generally "quiet" period of operation with little apparent conflict.

1931-1956 Construction of the lock and dam system on the Mississippi River occurred during this period, effectively negating the value of the reservoirs for supplemental navigation flows. The timber boom in northern Minnesota was over. Substantial population growth and extensive resort development occurred. Reservoir operations were also adjusted to provide flood protection for the City of Aitkin. The reservoirs were used to augment river flow in the Twin Cities area during drought periods in the years 1936-1936.

1956-1963 Recreation/tourism development accelerated rapidly and fluctuating water levels stimulated extensive controversy. The state took legislative action to extend its influence over reservoir operation. It mandated development of an operating plan and joint state/federal management.

1963-present That period represents a period of relative stability with respect to operation of reservoirs that should not indicate the period has been without controversy as evidenced by discussions of headwaters discharges during the 1976 drought and of course the current debate from 1988.

The Department of Natural Resources believes the current operating plan provides for reasonable operation of the reservoirs and a fair balance between competing interests. As evidenced in 1988, clarification is needed on authorities and procedures for low flow augmentation during drought periods.

## Panel II: REGIONAL PRECIPITATION AND CLIMATE TRENDS

**CHAIR: DONALD BAKER**
Department of Soil Science
University of Minnesota

That the climate is dynamic has seldom been more obvious than in the past 12 years, a period during which Minnesota experienced two droughts, (1976 and 1988) and perhaps the wettest 10 consecutive years on record (1977-1986). As a result, it is apparent we should plan for climatic variation. History shows that the variability in climate we have experienced recently is common. We were lulled into a false sense of security by the relatively brief period of a "benign climate" during the 1950s and into the 1970s.

Some facts about our climate and its variability are listed below.

### Precipitation

1. Records show it is highly variable both temporally and spatially.
2. There have been a number of "wet periods" and "dry periods," but there is no discernable long-term trend toward either in the historical record.
3. The wet and dry periods do not appear to be predictable, although there is a hint of approximately 20-year periodicity.
4. Changes from wet to dry and dry to wet periods have occurred with both great abruptness and as a slow progression.
5. The drought of 1988, while severe, is not unique in the climatological records. (The drought actually began in parts of the state as early as October 1986.)
6. The drought of 1988 has not ended for parts of the state.
7. The "greenhouse effect" need not be called upon to explain the 1988 drought.
8. The effects of most droughts (and surpluses) are exacerbated by our use of the land.

### Temperature

1. There is a detectable upward trend in temperature since about 1867 in Minnesota, with occasional retrogressions, most notably 1950-1965.
2. The warming trend was strongest from 1917 to 1939 in the northern hemisphere.
3. About 25-50 % of the temperature increase can be attributed to a natural increase following the "Little Ice Age."
4. Whatever the cause of the warming, it does not bode well for terrestrial water supplies.

**Climate Models and Data.** Predictions of future climate change are based on models that vary widely in complexity and sophistication. A few general comments about the usefulness and limitations of models should be kept in mind when reviewing climate projections made by various climate models. Although models often are used as predictive tools, they often are more useful in determining where our knowledge of a system is inadequate. A model is no better than the data supplied, and measurements entering the model are as important as the model. Relative to the present discussion, current climate models provide "scenarios" and educated guesses, not meteorological forecasts.

**Summary of Panel Presentations.** In the first paper J.A. Zandlo discusses events leading up to and occurring during the 1988 drought and provides us with some outlooks for the near future. The spector of serious change in our climate has been predicted by recent climate modelling efforts. The second paper, by H.E. Wright Jr. addresses this issue from an unusual and fascinating vantage point. Pollen analysis is used to provide an estimate of past vegetation distributions. From this evidence, inferences are made on the associated climate in past times. Based on model-derived temperature and precipitation scenarios, expected vegetative conditions of the future can be predicted. In the third paper, R.H. Skaggs and D.A. Brown show how estimates of future water supplies can be derived. In this case, a model was tested against measured data and correctly estimated the Mississippi River flow at St. Paul. Based on this validation, the authors then determined what river flow would be under temperature conditions projected by climate modelers.

## Aspects of the 1988 Drought and Outlooks

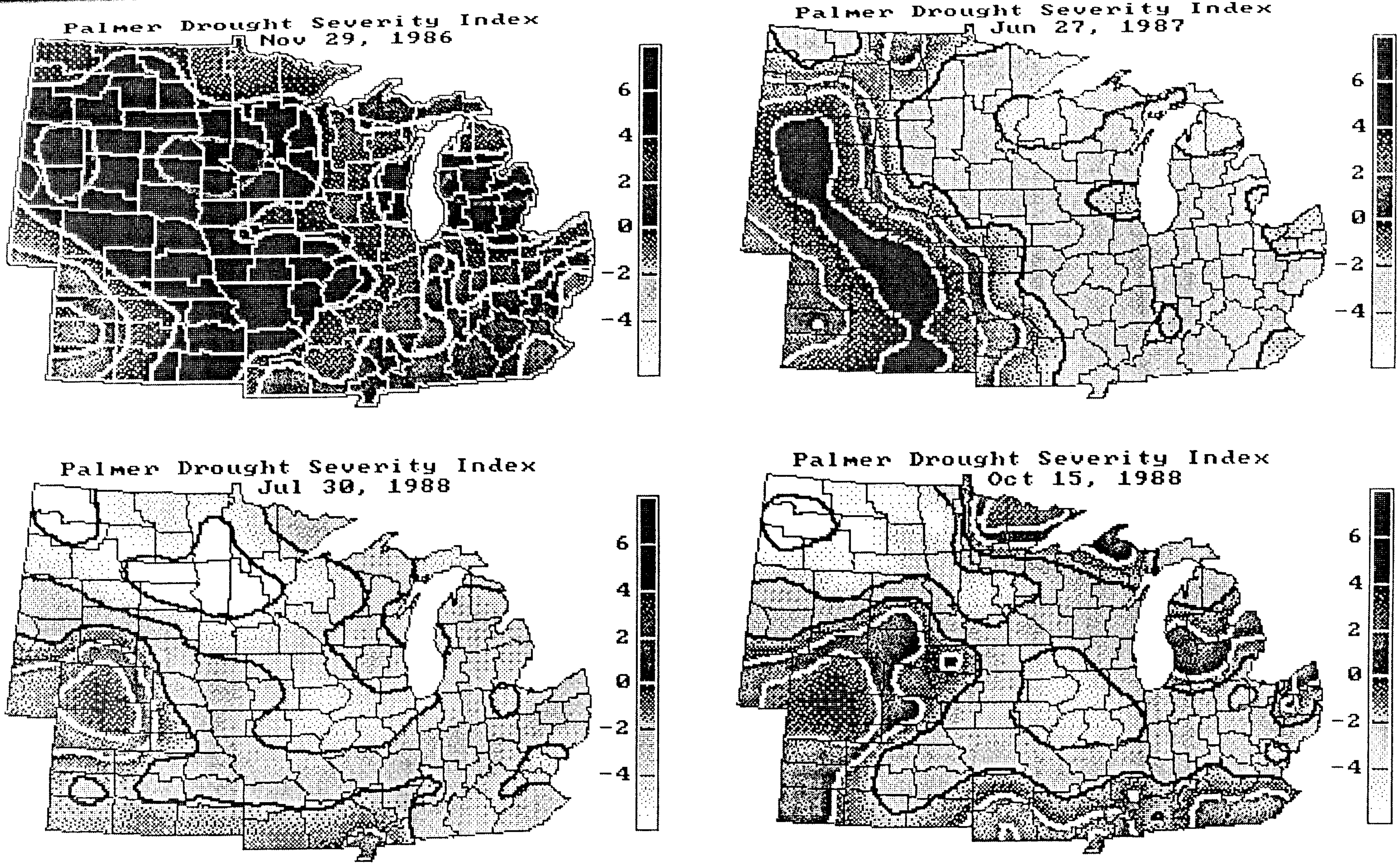
James A. Zandlo, State Climatologist, Division of Waters, Minnesota Department of Natural Resources, St. Paul, MN

The drought of 1988 will be remembered as one of the great droughts in the history of the United States. More areas were afflicted with severe or extreme conditions in 1934 and more "100+ degree days" were recorded in the Midwest in 1936, but the 1988 drought was unique in many ways.

Some of the worst conditions during summer 1988 occurred along the northern tier of states from Minnesota to Montana. Figure 3 shows spatial variations in the widely used Palmer drought index in fall 1986 prior to the start of the drought and in summer 1987, when drought conditions actually began, and in summer and fall of 1988, during the height of the 1988 drought. In Minnesota, the summer of 1987 reduced long-term surpluses of moisture so that moderate to severe drought conditions were present at the end of the 1987-88 winter. Record low precipitation and high temperatures quickly intensified those moderate conditions into the extreme conditions which lingered into November 1988 and beyond.

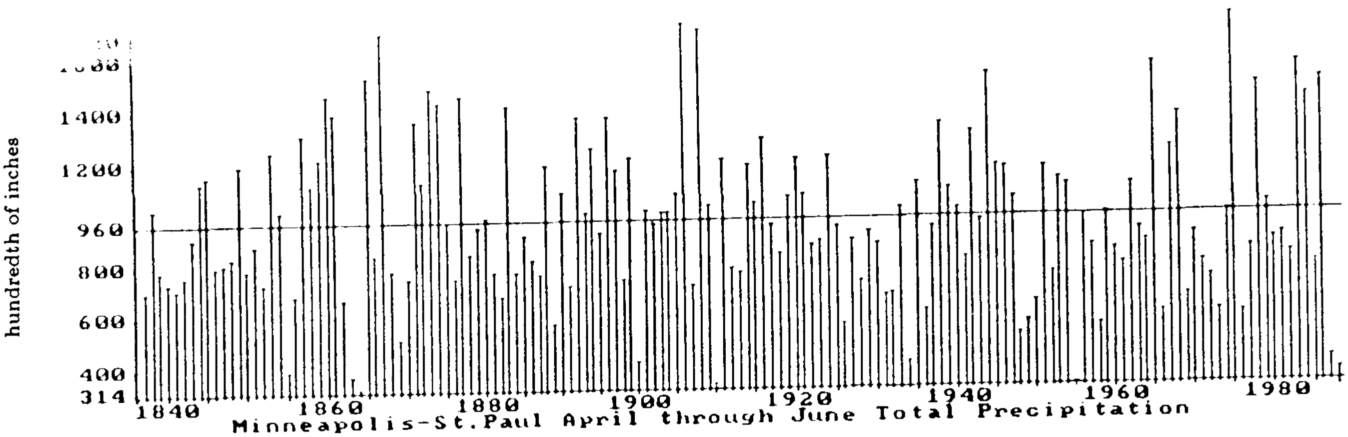
It is worth noting specific records that were broken. These are based on statewide averages from records extending back to 1891 (see Figure 4).

1. June averaged 1.33 inches of rain, replacing the old record of 1.50 set in 1910. (No other single months were record beaters.)
2. April through July precipitation of 5.64 inches broke the old record of 6.44 inches in 1936. (Lesser periods ending with July were also record setting.)
3. May through August temperature at 70.4°F was 2.5° warmer than the old record set in 1936! (Shorter periods starting with May were also record setting.)
4. Minneapolis-St. Paul Airport had 44 days with 90°F or hotter. The old record had been 36 days for 1936.
5. The Palmer Drought Index dropped to -8 in northwest Minnesota for the first time in modern records (since turn-of-the-century). The old record had been 6.0 in September 1934. Other parts of the state retain their old record values from 1934.




Positive values indicate WET conditions.
Levels of DRYness: -1 to -2 is Mild, -2 to -3 is Moderate, -3 to -4 is Severe, less or equal to -4 is Extreme drought.

Figure 3. Iso-maps of the Palmer drought severity index for the Upper Midwest and Great Plains states for four dates. Note presence of drought conditions in parts of region in summer of 1987 and the much more severe drought conditions in much of Minnesota during summer of 1988.



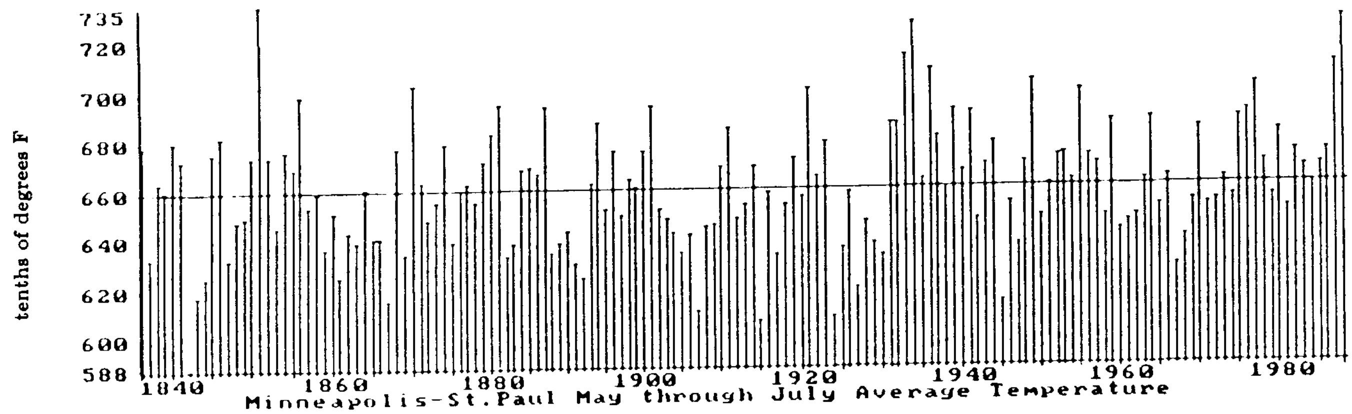




Figure 4. Summary of April-June precipitation and May-July average temperatures in the Twin Cities for the period of the climatological record.

6. Unofficial and relatively short-term records at St. Paul indicate the April through July period experienced about 20% more solar radiation than the station long-term average. The May through July pan evaporation was 40 percent above average.

Dry conditions, essentially unchanged through the winter of 1987-88, were not ameliorated by normal spring rainfall. In fact, they were exacerbated by extremely high temperatures. Any natural or man-made environment dependent on the natural hydrologic cycle started the warm season in a stressed state and experienced little or no relief until late summer when more precipitation began to occur and temperatures moderated.

In mid-November 1988, roughly one-third of Minnesota was still classified as in a state of extreme drought. The northwest and central parts of the state still require approximately seven inches of precipitation over normal amounts in order to reduce the Palmer Drought Severity Index to near zero. As we move into the cold months of the year, convective storms with very heavy rainfalls have generally been replaced by larger scale precipitation patterns with less intense precipitation events.

With lower intensities, runoff will be less common in the driest areas as the soil surface absorbs more precipitation. Conversely, soil moisture is best replenished by fall precipitation. Soil moisture increased generally by 1-2 inches between September 1 and

November 1, 1988. Additional increases have occurred since November 1 with continuing rainfall. Winter precipitation, mostly snow, accumulating on frozen ground, will not be as available for soil moisture recharge but it will runoff to rivers and other surface waters.

The National Weather Service predicts Minnesota will probably be slightly warmer than normal and receive below normal precipitation November through January. For the near-term (mid-November through mid-December), the outlook is for near normal temperatures and heavier than normal precipitation. Conversely, with the globe's return to an "anti El Nino" or "la Nina" conditions, some researchers suggest that the northern tier of states will experience a colder than normal winter (Nature, 8/26/88).

For a longer forecast, the best guess is that the weather will return to normal conditions. Such a climatological forecast indicates that extreme drought tends to last less than 12 months in all climate regions in Minnesota. However, during the early 1930s, extreme drought lasted as long as 40 months in our west-central region. Thus, if no climate change has occurred, and the past can be used as a model for the future, extreme drought will end before the middle of next summer in most of Minnesota. There is a small chance it may continue for another year or even two.

Conditional climatic outlooks go beyond simple climatology. Using the phase of the sunspot cycle, researchers have produced a "solar influenced climatological forecast" of precipitation. Paul Waite, former state climatologist for Iowa, suggested that 1987 would be dry in Iowa. (Most Iowa climate regions ended up dry in 1987, but two very wet regions brought up the state average to a positive value. Minnesota was dry in both 1987 and 1988.). He suggested that ensuing years up to the early 1990s would revert to a relatively moist pattern. However, based on the phase of the lunar nodal cycle, both indicating dryness, he says the "next major drought cycle should begin near 1991 or 1991." Obviously, recent results point out weaknesses in such a forecast.

Global climate modeling has been used to attempt climatological forecasts. Such models can have influences such as varying solar output or a changeable level of $CO_2$ in the atmosphere. The interactions of the real atmosphere-surface system are modeled by mathematical relationships. However, in a feedback process, a relatively minor change in the Greenhouse Effect may elicit rather substantial changes. Consider, for instance, that clouds reflect away incoming solar radiation. If the average temperature near the Earth's surface is increased, one would expect the tendency to evaporate water from the surface would increase and the amount of moisture in the atmosphere would also increase. How will the amount of cloud cover change? Perhaps more importantly, how will the change in cloud cover affect the amount of radiation reaching the Earth's surface to warm the surface air? Generally, if the cloud cover is increased, the Greenhouse Effect will be lessened; if decreased, it will enhance the effect.

Climate model results have also been scrutinized for their ability to portray what has already transpired. The model-generated climatic statistics indicate precipitation levels substantially above what has actually been observed. Further, the upward trend in temperature over the last century or so has tended to be overestimated by a factor of two or more. Finally, some of the verification data itself has been scrutinized and found to have deficiencies. Station siting and time-of-observation changes can influence the apparent results (Michaels, 1988). Further, one heavily used time series shown this summer depicted a rising northern hemisphere temperature for the last 100 years. But there is evidence that preceding decades experienced decreasing temperatures.

What are we to make of these soothsayers? In the short-term, reliable indicators imply near normal to benign weather conditions relative to our current drought. Further, climatology indicates that a return to near normal conditions is also most likely. However, the hydrological systems affected by nearly two years of drought will be slow to respond. Generally, during the period of unfrozen ground, precipitation will immediately and directly affect soil moisture reserves. Since soil moisture generally reaches its lowest levels near the end of the growing season, even virtually dry soils, though proportionally very dry, cannot have large departures in inches from their normal state. Fall rains, accompanied by normally cool fall temperatures, have led to partial recovery of soil moisture in much of Minnesota. Lakes and rivers will probably be slower to recover since they are more dependent on runoff for replenishment. Groundwater can be expected to gain only after lake and rivers have returned to near normal.

Even if the Greenhouse Effect has begun, the conditions of 1988 should still be considered an infrequent event rather than as a commonplace feature of our climate. With a 100% increase in $CO_2$, in the middle of the continent greenhouse effect modeling efforts indicate temperature increases of a few to several degrees centigrade and decrease in soil moisture of an inch or less. While this year's late spring and early summer temperature departures of 5-7°F (and greater) and soil moisture deficits of several inches look worse than the average condition of a greenhouse-warmed world, they may be more likely to occur over the next few decades. If hotter and or drier years become more likely or more frequent, hydrologic systems, as shown in the 1920s and 1930s will show definite long-term downward trends.

**Long-term Climate Projections**

Herbert E. Wright, Director, Limnological Research Center, University of Minnesota, Minneapolis, MN

Long-range predictions depend in part on whether one can identify past climate cycles and believe they will continue into the future. Paleoclimatic studies show that in Minnesota the last glacial maximum occurred about 20,000 years ago. A warming trend prevailed until about 7,000 years ago, when the prairie/forest border was more than 100 miles northeast of its present position and when lake levels and groundwater levels were low (Figure 5). These could result from a mean annual temperature 1-2°C higher than today. Since that time the climate has become cooler and wetter, resulting not only in the westward movement of the prairie/forest border and the southward expansion of spruce forest but also in the development of the great peatlands of the Red Lake area in northern Minnesota. The Little Ice Age, which began about 1200 A.D. (ending the Viking

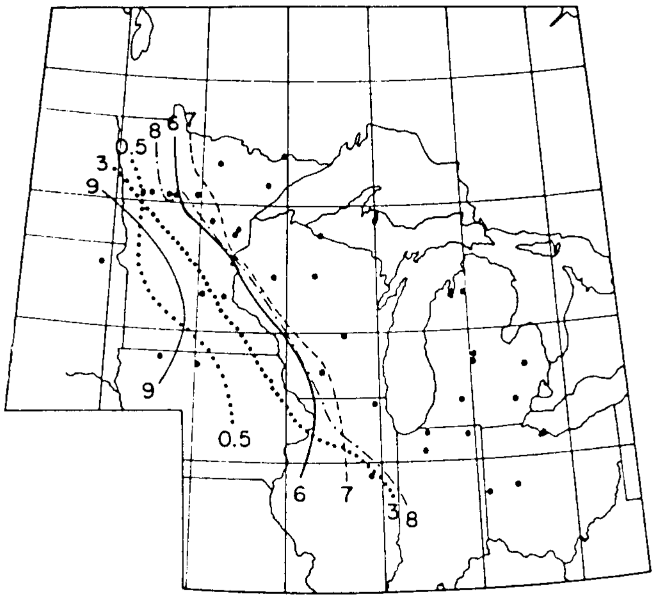



Figure 5. Map showing the position of the 20% isopoll for prairie-forb pollen from 9000 to 500 yr B.P. with higher percentages to the west. Changes in position are interpreted as indications of the changes in the prairie/forest boarder. Numbers associated with lines represent thousands of years before present. (Webb, Cushing, and Wright, 1983, Holocene changes in the vegetation of the mid-west).

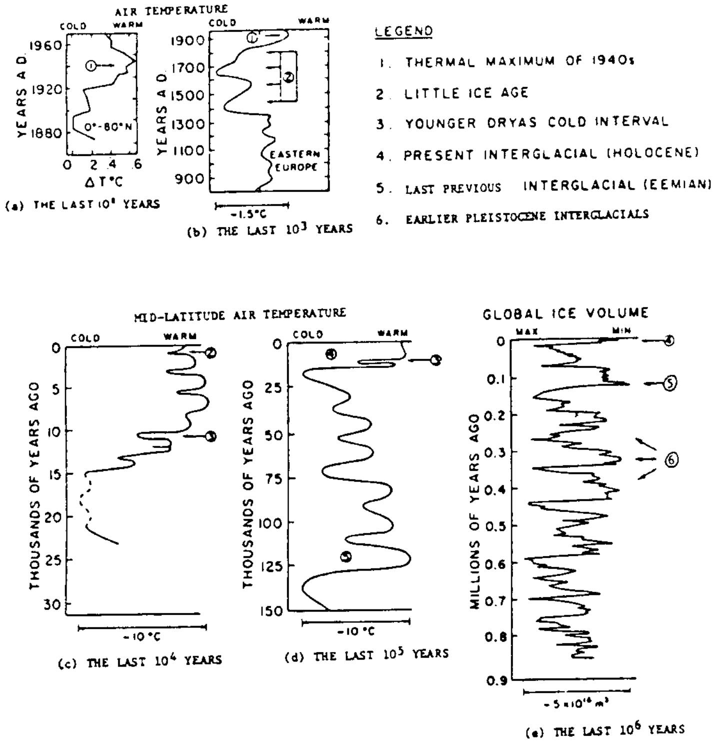



Figure 6. Generalized trends in global climate: the past million years. (a) Changes in the five-year average surface temperatures over the region 0-80°N during the last 100 years. (b) Winter severity index for eastern Europe during the last 1000 years. (c) Generalized midlatitude northern hemisphere air-temperature trends during the last 15,000 years, based on changes in tree lines, marginal fluctuations in alpine and continental glaciers and shifts in vegetation patterns recorded in pollen spectra. (d) Generalized northern hemisphere air-temperature trends during the last 100,000 years, based on midlatitude sea-surface temperature and pollen records and on worldwide sea-level records. (e) Fluctuations in global ice-volume during the last 1,000,000 years as recorded by changes in isotopic composition of fossil plankton in deep-sea core V28-238. See legend for identification of symbols (1) through (6). Components of diagram derived from various sources; diagrams from Understanding Climate Change, a Program for Action, 1975, a publication of the National Academy of Science. H.E. Wright.

era of North American exploration), was the strongest global climatic cooling since the end of major continental glaciation 10,000 years ago. It may be an intensification of the cooling trend of the last 7,000 years. (See Figure 6 for some general trends in climate for time scales ranging from the past 100 to past million years.)

The glacial/interglacial cycle can be explained by changes in the distribution of solar energy as controlled by the tilt of the earth's axis and other astronomic factors. Previous interglacial intervals have lasted only about 10,000 years. On this basis the cooling trend should continue; the next glacial maximum is predicted for about 23,000 years in the future and the next major glaciation about 60,000 years from now. Ice-core records from Greenland and Antarctica show that the $CO_2$ content of the atmosphere during past glacial periods was about 200 ppm, compared with 280 ppm during the postglacial period and 340 ppm today. This demonstrates the close correlation between $CO_2$ and climate.

Superimposed on this long cycle are temperature fluctuations of shorter duration, as illustrated by paleolimnological studies on Devils Lake in eastern North Dakota (Figure 7). Past salinites were inferred from the trace-metal composition of ostracod shells in sediment cores. After an early freshwater phase, about five major fluctuations can be identified during the last 8,000 years. Measurements at Devils Lake during the last 100 years show that salinity increased when the lake level lowered to its minimum in the 1940s as a result of the dry climate. Superimposed on these are still shorter changes, culminating in the low-water episode of the 1940s at Devils Lake, as recorded also by weather data.

Relative to predicting future climatic conditions from past climate cycles, all bets are off if the content of atmospheric $CO_2$ and other trace gases is increased by fossil fuel combustion and rapid deforestation. One could argue that the Little Ice Age signals the beginning of the end of the present 10,000 year interglacial period, and that the warming trend of the last 100 years has been caused by the greenhouse effect.

Doubling of the atmospheric greenhouse gases by the mid 21st century almost certainly will increase mean annual temperatures by 3°C, with higher values at higher latitudes, according to several different climate models. This is much more than the estimated temperature change of 7,000 years ago. Changes in the prairie/forest border, the composition and vigor of the forests of northern Minnesota, levels of lakes, river flow, and groundwater will be much more drastic with this temperature increase. Rapidity of the changes will cause substantial disruption in established patterns of land use, availability of water resources, of timber production, and many other elements of the economy. Research on past climate changes provides only a partial guide to future considerations.

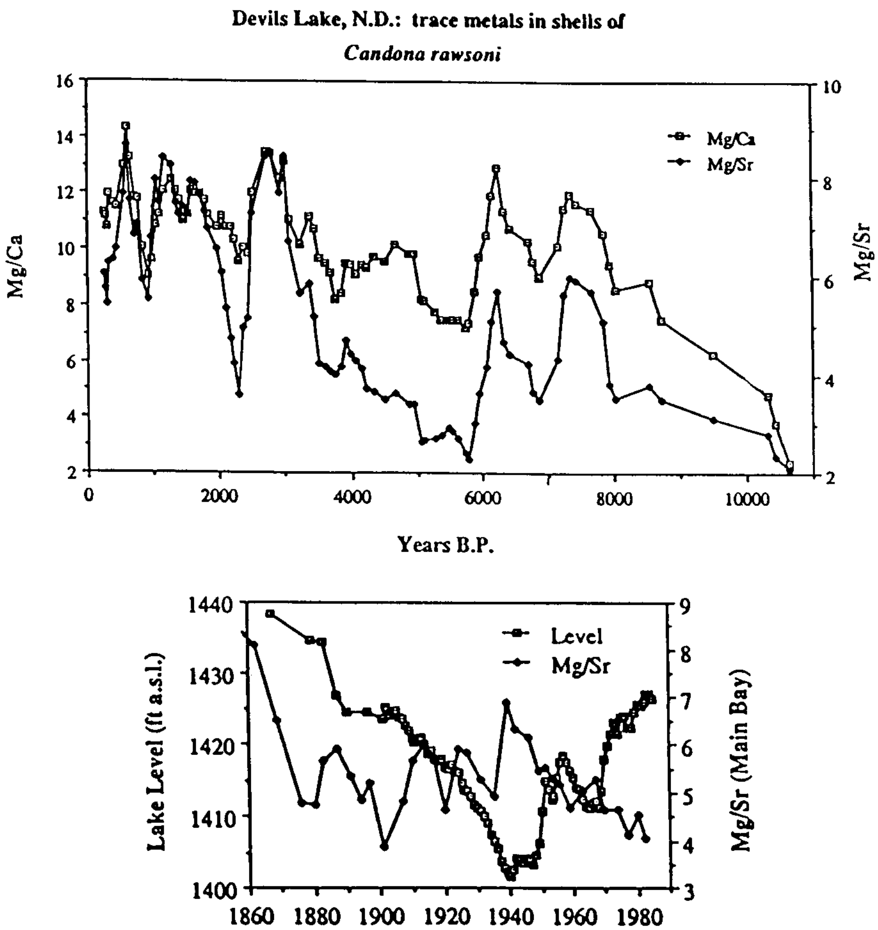



Figure 7. (upper) Mg/Ca and Mg/Sr ratios in ostracod shells from sediments of show similar temporal patterns, and (lower) water levels (and salinity) in the lake appear to be related to Mg/Sr ratios in the shells.

## Climate and the Flow of the Mississippi River at St. Paul

Richard H. Skaggs and Dwight A. Brown, Department of Geography, University of Minnesota

**Introduction.** Explaining past variations or predicting future fluctuations of Mississippi River flow requires that we establish links between flow volume and the factors that control it. We have developed a statistical model that describes the relationships between atmospheric moisture surplus and flow of the Mississippi River at St. Paul.

We selected the mean annual and mean July flow of the Mississippi drainage at St. Paul as crude but robust measures of the available water in a large system. We use climatological division climate data for the six Minnesota climatological divisions that contribute to flow of the Mississippi at St. Paul (Figure 8).

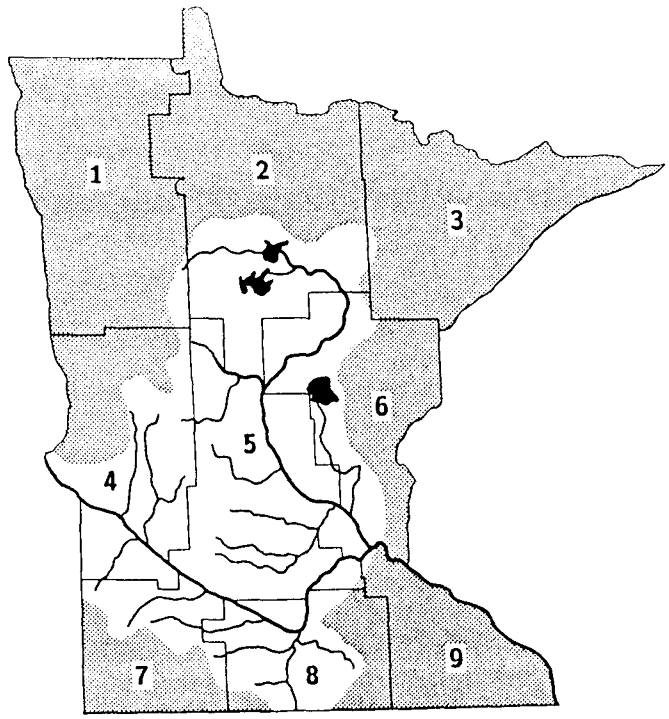



Figure 8. Climatic divisions of Minnesota and the Mississippi River Basin above St. Paul, MN (Skaggs and Brown, 1987).

**Problem Statement.** Concerns about the impact of drought and climate change on water resources of the Twin Cities metropolitan area prompted us to address three questions on the sensitivity of Mississippi River flow to these changes.

1. To what degree is the computed water budget surplus statistically related to the observed mean annual and mean July flows of the Mississippi measured at St. Paul?
2. Are the observed fluctuations in the annual flow caused by fluctuations in climate?
3. Will a sharp temperature increase greatly affect water surpluses and reduce a major water resource of the state?

**Data, Methods, and Analysis.** We constructed the statistical flow models with the regression methods described previously (Skaggs and Brown 1987), in which the variables to be predicted are (1) the mean annual flow of the Mississippi, (measured at St. Paul for calendar years) and (2) mean July flows. The predictor variables are the summed monthly or individual monthly water budget surpluses for each of the six contributing climatic subdivisions that contribute water to the river (Figure 8).

A graph of smoothed data (Figure 9) clearly shows that mean annual flow declined regularly from the early 1900s to the late 1930s. There was a sharp increase in the mean annual flow in the late 1930s and early 1940s. After the mid-1940s there is little evidence of systematic fluctuation in the mean annual flow, although the past few years seem to trend strongly upward.

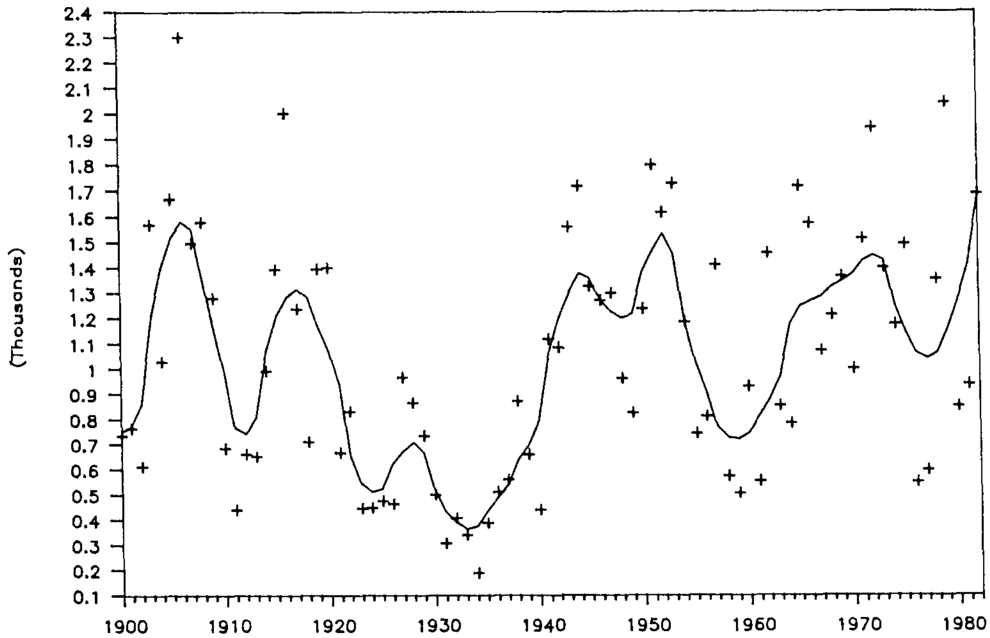



Figure 9. Smoothed (line) and observed (+) mean annual flow of the Mississippi River at St. Paul, MN in cubic feet per second (Skaggs and Brown, 1987).

Total precipitation and mean temperature were used to compute monthly water budgets for divisions by Thornthwaite's (1948) method. We used the algorithm developed by Willmott et al. (1985) because it incorporates a more realistic treatment of snow melt than previous methods.

We estimated flow (the dependent variable), with stepwise multiple linear regression, which selects a subset of predictor variables that are more or less independent. For the mean annual flow analysis, the independent variables were created by summing the monthly surpluses over the calendar year, giving a total annual surplus for each of the six climatological divisions. These time series of annual surpluses are the independent variables.

A similar approach was taken to predict mean July flow. The potential predictor variables were the monthly computed surpluses from April, May, and June of the current year and from September, October, and November of the prior year for each of the six climatological divisions. In addition, the July mean flow of the prior year was included to account for the serial correlation in the dependent variable.

The statistical models were developed with data from on only the first half of the record to allow us to predict the second half of the record and determine how well the model works on "independent" data. Good performance of the model on the second half of the record is evidence that climatic fluctuations are major contributors to the observed differences in the mean annual or mean July flow of the Mississippi.

Results:

**Predicting Mean Annual Flow.** The model predicted quite well fluctuations in the mean annual flow in both the first and second parts of the record with 70 percent explanation of the variance (Figure 10). The mean of the observed annual flow for the full record is 10,418 cfs while the mean for the full record for the estimated (predicted) mean annual flow is 10,383 cfs. The corresponding standard deviations are 4,818 cfs and 4,817 cfs. The stepwise regression procedure chose the annual surpluses for division four and six as predictor variables.

Comparison of the first and second halves of the record reveals that the predicted and actual mean annual flows are identical in the first half of the record (8,699 cfs) while the standard deviations are 4,188 cfs (predicted) and 4,956 cfs (actual). In the second half of the record, the means of the predicted and actual flows are slightly different, 12,027 cfs and 12,097 cfs respectively. The corresponding standard deviations are 4,867 cfs and 4,077 cfs.

**Predicting July Mean Flow.** The stepwise selection procedure chose the April, May, and June surpluses from division 4 for the current year, the division 6 June surplus for the current year, and the flow from the prior July. About 85 percent of the variance in July mean flow is explained by these variables. The predicted mean July flow is quite good in most instances (Figure 11). The major difficulty with the July model is that it is a poor predictor of extremely low flows.

**Flow Response to Climatic Fluctuations.** In attempting to answer our second question, whether the increased mean flow since the late 1930s is largely the result of climatic fluctuations, we used the regression model results for the mean annual flow. If we compare the two predictor variables (surpluses in divisions four and six) for the two halves of the record, statistically significant differences are evident. The division four mean surplus is 43 mm for the first half and 88 mm for the second half. For division six, the first and second half means are 144 mm and 181 mm respectively.

The combination of good performance by the model in the second half of the record and the significant differences in the predictor variables leads us to conclude that the increase in mean annual flow of the Mississippi at St. Paul in the last 41 years was largely the result of a fluctuation in the climate, as measured by the computed surplus, (with much larger surpluses since about 1940). The increased surpluses computed with the Thornthwaite method can arise from an increase in precipitation, a decrease in potential evapotranspiration, or a combination of the two. Comparison of the two halves of the precipitation and computed potential evapotranspiration records with t-tests indicate that the computed potential Figure 10 evapotranspirations are not significantly different, but that the observed precipitations are. Thus, the last 41 years has been a relatively wet period with a significant increase in surplus moisture, which has been translated into a significant increase in mean annual flow.

**The Effect of Doubling Greenhouse Gasses.** Researchers predict a rise of 3°C in the global mean annual temperature. Because temperature changes affect water balance by changing evapotranspiration, we investigated the impact that such a substantial temperature increase might have on annual river flow. Our results

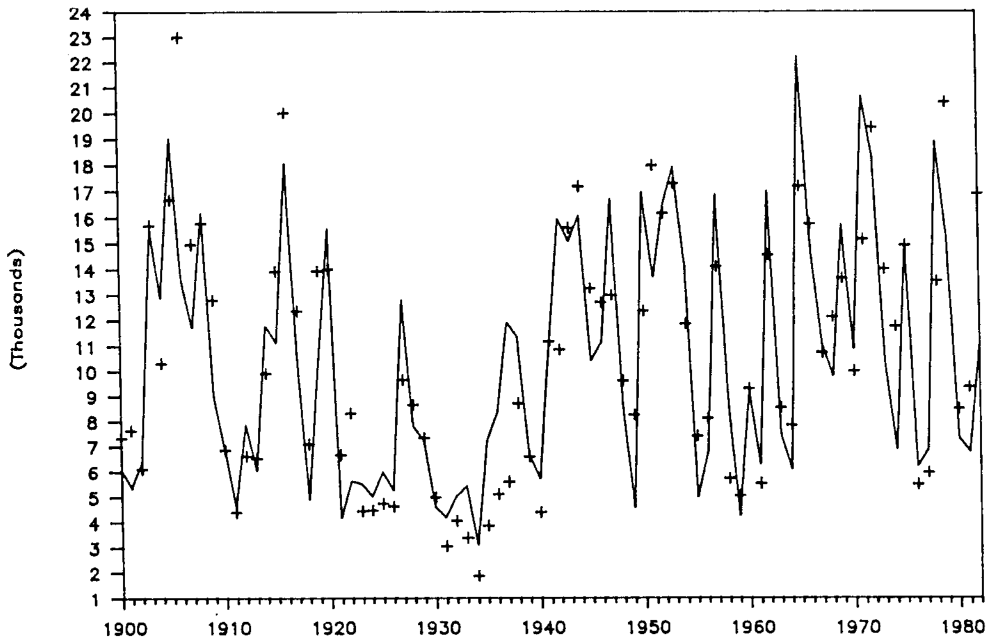



Figure 10. Predicted (line) and observed (+) mean annual flow of the Mississippi River at St. Paul, MN in cubic feet per second (Skaggs and Brown, 1987).

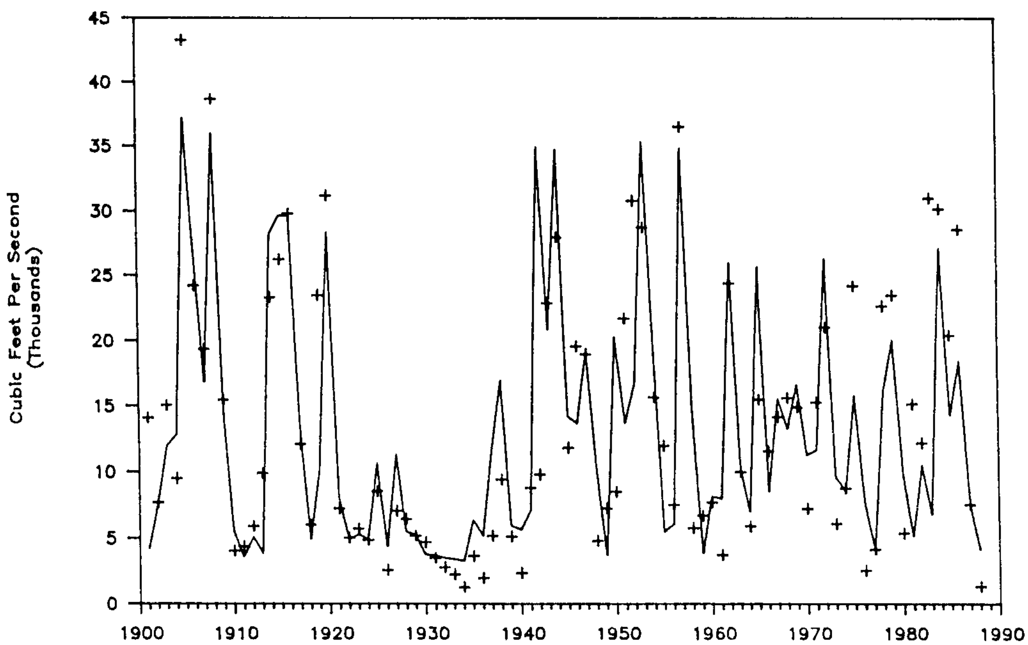



Figure 11. Predicted (line) and observed (+) mean July flow of the Mississippi River at St. Paul, MN. (Skaggs and Brown, 1987).

are only a first, and rather crude, estimate because of the many assumptions made. We assumed that the increase in Minnesota's temperature will be 3°C, the same as the global average. We further assumed that the temperature rise will be concentrated in the winter, and we rather arbitrarily assigned a rise of 4°C in the six winter months and a rise of 2°C in the six summer months. Finally, we assumed that precipitation is not changed. These assumptions are conservative because the temperature change at higher latitudes is predicted to be larger. Thus, we think that these are the minimal impacts.

For the years 1971 through 1983 and divisions four and six, we recalculated the Thornthwaite water budgets using average temperatures increased by the postulated amounts. There is a sharp decrease in computed surplus (Figure 12). In division four, the average annual surplus changed from 82 mm to 36 mm per year, a decrease of 56%. The average surplus computed for division six decreased by 45% (from 203 mm to 112 mm per year). Given the importance of the surpluses in these two division to the mean flow of the Mississippi River, it is clear that a major temperature increase would affect the water resources of the state.

Droughts focus our attention on low flows such as we experienced in July of 1988. The statistical model presented here performed very well overall. However, the flow rates experienced during severe droughts is not determined by water budget surpluses in the preceding time period but by *long-term* surpluses that affect groundwater levels. Unfortunately, the latter are also influenced by rates and location of groundwater withdrawals. Thus, it appears that the water budget surplus method for predicting annual or monthly flows may not be an accurate method to predict the low flows experienced during under a warmer climate because surpluses may not be produced for an extended period of time. This limitation highlights the importance of developing different methodologies to estimate the effect of climate change on low flow conditions.

Finally, we should put the past 80 years of fluctuations of water budget surpluses in a longer term context. Although long-term data for the contributing subdivisions are not available, it is possible to build a synthetic temperature and precipitation record for the Twin Cities. This record has been used to determine the long-term water budget and to graph the surplus relative to the long-term mean (Figure 13).

Any analysis of the hydrologic effects of climate change must be cast within the range of fluctuations that have already occurred. These include a wide range in surpluses, a long history of persistence, and an appreciation of the fact that the recent wet period that produced high flows and problematic lake levels was preceded by 50 years of relative dry conditions. That period was preceded by a longer and wetter period than we have experienced in the 1980s. There seems to be no recent trend toward greater deviations from the long-term mean water balance.

**Conclusions.** The mean annual flow of the Mississippi River at St. Paul has been significantly greater in the last four decades of this century. The increase in mean annual flow is closely related to increases in water balance surpluses. These increases are at least partly due to increased precipitation. The surpluses computed in the Thornthwaite water balance method can be used to estimate (and simulate) water availability at least at this large spatial scale.

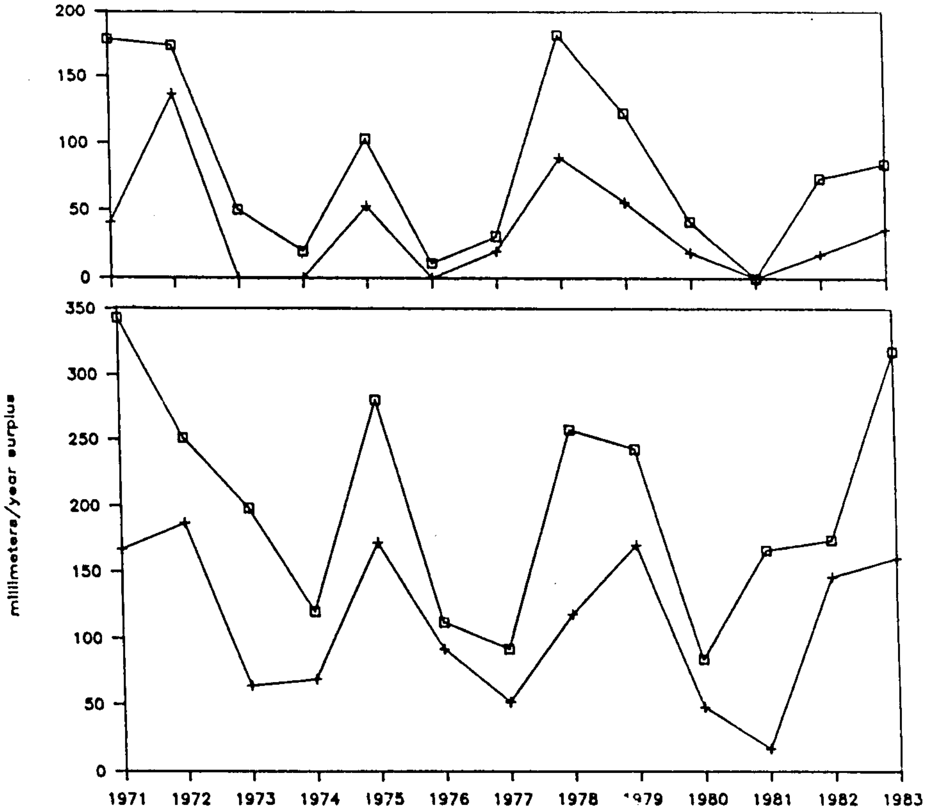



Figure 12. The response of water budget surplus to temperature increases for Minnesota climatic divisions 4 (upper) and 6 (lower).

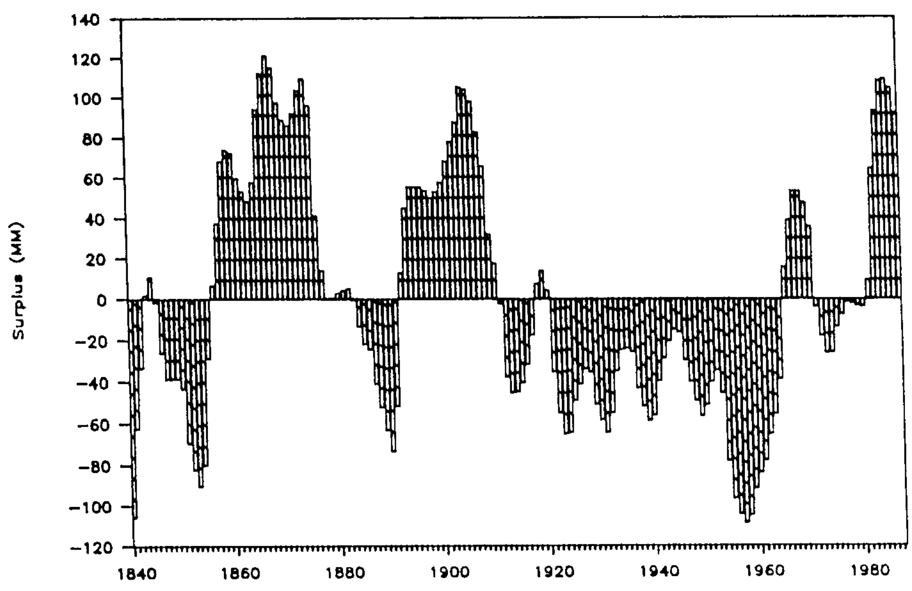



Figure 13. Deviations from the long-term mean of annual water budget surplus for the Twin Cities Minnesota.

Water budget surpluses are affected by temperature changes, and our crude estimates indicate that projected temperature rises are large enough to severely decrease the water resource base of the state.

The excellent performance of the statistical model, based on the stepwise regression procedure, allows us to investigate the statistical properties of the time series of surplus for divisions four and six. However, our results show we need to develop different methodologies to estimate the effect of climate change on the low flows, which have a poorly defined relationship to short-term climate fluctuations. Adequate data to develop statistical models to predict the effects of temperature rise on soil water, groundwater, and base flow do not exist. To do these, we need physically-based simulation models that preserve the continuity of the hydrologic cycle and geographical information to properly handle the data and manage the output maps of the simulations.

References and Acknowledgements

We thank the St Paul Office of the U.S. Geological Survey, Mark Seeley, and Jim Zandlo, Minnesota Department of Natural Resources, for providing data.

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**Panel III: ANATOMY OF THE METROPOLITAN AREA WATER USE SYSTEMS**

**CHAIR: GARY OBERTS**
Metropolitan Council, St. Paul, MN

Presentation Summary

Water use in the metropolitan area is summarized in Table 3. The water *withdrawal* figures show the dominance of use for power plant cooling, but *consumption* figures show a rather balanced demand among several users. Power plant cooling consumes little water and its dominance for withdrawal diminishes, and this results in a switch of source dominance from 75% surface water for withdrawals to 67% groundwater for consumption.

With various users competing for a finite volume of water, some supply difficulties arise. The problem of adequate supply among Mississippi River users was the most serious surface water problem we faced during the drought of 1988. As flow on the river drops, users are forced to adjust their operations and, in many cases, pay for additional supply. The first user to experience difficulties in 1988 was the Metropolitan Waste Control Commission (MWCC). Their problems and solutions are described in the summary by Don Madore. In short, MWCC was forced to aerate effluent in order to maintain river oxygen levels. The scheme worked well and water quality problems were avoided. Navigation problems were minimal. Power plant impacts are described by Dave Heberling.

The press emphasized water supply problems of Minneapolis and St. Paul. Evaluation of the total demand for water shows this emphasis was misplaced, since peak demand by both cities was less than 200 million gallons per day (mgd). Flow in the vicinity of the two city water intakes reaches a minimum (on one day only) of 545 mgd (842 cfs). St. Paul switched its intake pattern to draw more water from its lake and groundwater system. Both cities instituted conservation programs that were effective in reducing demand. There is no doubt that Minneapolis needs a backup system for emergencies. But it could maximize its surface water withdrawals to take advantage of water that will be lost downstream if not used by the city.

There have not been many groundwater supply problems in the metropolitan area. Growth patterns of the region, however, indicate that most growth for the next 20 years will occur in areas supplied by groundwater. Projections of water needed to supply this growth in the second ring suburbs indicates a need for over 80 new high capacity wells. In addition, there will be commercial/ industrial growth that might require another 25 wells. This number is very rough since it is difficult to predict commercial/industrial growth. Finally, Minneapolis and St. Paul might be looking to groundwater to supply as much as 75 mgd.

This calculated regional demand for up to 350 mgd of groundwater (not including Minneapolis and St. Paul), coupled with the recent down-sizing of groundwater capacity by USGS to 650 mgd, means that by the year 2000 we will be using one-half of the available groundwater in the region. Adding 75 mgd from the Twin Cities would mean we will be closer to two-thirds of supply. During the summer of 1988 supply shortages occurred when several municipal users had dry well

Table 3. Water Use Summary for Metropolitan Twin Cities in 1980*

| | |
|---|---|
| Total Water Withdrawals - | Groundwater = 246 mgd<br>Surface water = 749 mgd |
| Total Water Consumption - | Groundwater = 45.7 mgd<br>Surface water = 23.4 mgd |
| Surface Water Withdrawals - | Power plant cooling = 651 mgd<br>Residential = 66 mgd<br>Commercial/Industrial = 32 mgd |
| Surface Water Consumption - | Power plant cooling (summer 1988 actual pumpage)<br>= 9 mgd from St. Croix River<br>= 1.3 mgd from Mississippi River<br>= 0.65 mgd from Minnesota River<br>Residential = 6.6 mgd<br>Commercial/Industrial = 3.5 mgd<br>Agricultural = 0.3 mgd |
| Groundwater Consumption - | Agricultural = 17.6 mgd<br>Commercial/Industrial = 86 mgd<br>Temperature control = 24 mgd<br>Agricultural = 18 mgd<br>Miscellaneous = 5 mgd |
| Groundwater Consumption - | Agricultural = 17.6 mgd<br>Commercial/Industrial = 12.1 mgd<br>Residential = 11.3 mgd<br>Miscellaneous = 4.7 mgd |
| Mississippi River "Use" - | Low design flow (7Q10 at Anoka for assimilation of wastewater = 800 mgd<br>- NSP's Riverside power plant = 350 mgd<br>- Navigation at SAF = 225 mgd<br>- Peak Mpls-St. Paul water = 200 mgd<br>- July, 1988 low flow = 545 mgd |

High Capacity Municipal Wells in Developed/Developing Area -
- Existing/Permitted 1988 = 380
- Projected need 2000 = 82
- Mpls-St. Paul possibly up to 75 mgd

Additional Industrial/Commercial Wells - projections difficult but appears as though 25 large capacity wells possible

*From "Water Use in the Twin Cities Metropolitan Area: An Update", Gary L. Oberts, Metropolitan Council Publication No. 10-84-086, May, 1984 with revisions based on data presented at the conference.

intakes. Although the shortages were not permanent, they were indicative of demand exceeding supply, a condition that may worsen in the near future.

Last summer's supply problems raise many questions on appropriate water use. Should we allow approximately 25 mgd of groundwater, used for once-through cooling of buildings in the central cities, to escape down storm sewers, or should we try to capture those discharges and put the water to further use? Should we try harder to maximize use of surface water before it disappears downstream? What do we need in terms of planning to avoid disaster during the next drought? This year, disaster was averted when it rained in August, but there is no assurance that we will be so lucky next time. Have we learned to be pro-active before the next drought, or will our complacency mean we will again be merely reactive?

**Issues/Questions**
**Panel consensus/answers**

1. Was there really a water shortage in the summer of 1988 or was there plenty of water available for all users?

There certainly was less water compared with normal operating years, but the shortage did not result in major conflicts among metropolitan area users. All users within the region were able to adapt to the lower flow and avert a crisis. The MWCC was the first to experience difficulties but these were easily overcome by aerating the effluent as it was discharged so that water quality problems were avoided. Water shortages were never serious as far as Minneapolis and St. Paul were concerned. Flow remained well above critical levels and both cities instituted conservation measures merely as a gesture of cooperation and goodwill. Power plant cooling problems within the region were not serious, although some difficulties were experienced in upstream plants. Navigation was limited but no serious flow shortages were seen. The panel generally felt that the drought of 1988 was portrayed in the press as far more serious than it actually was for metropolitan area users. More serious problems were averted by rain.

2. Which user(s) reached a critical supply level first and what action should this trigger?

The first user to experience problems was MWCC, as explained above, but, the MWCC was able to adopt and treat its effluent to such an extent that the river water never fell below oxygen standards. Most of the surface water (9 of the 11 mgd) consumed by Northern States Power (NSP) in the metropolitan area comes from the St. Croix River at the King plant, not from the Mississippi River. NSP does, however, consume a maximum of 37 mgd at its Sherco and Monticello plants upstream of the metropolitan area. NSP was unable to maintain full load generating capability at Monticello due to low river flows and high river temperatures. At times the Monticello plant was limited to 70% of its generating capacity because of cooling water problems.

Minneapolis and St. Paul can operate with very low flows, but Minneapolis should have a backup system in the event shortages persist indefinitely or there is a serious upstream spill that would force intake closure for longer than one day.

3. What costs are involved when a user must make up for a water shortage?

MWCC incurred a cost of $1,500 per day to aerate its effluent. MWCC was forced to aerate from June 2 through October 7 to ensure adequate effluent oxygen levels, for a total cost close to $200,000. NSP estimates replacement power purchases cost its typical residential customer $0.07 to $0.09 for each summer week that the Monticello plant was limited to 75% capacity.

Jim Hayek estimated that Minneapolis citizens lost or will lose over $5 million in damage to lawns, trees, and shrubs. He believes this figure might be quite conservative after all damage is repaired. Verne Jacobsen could not put a value on St. Paul losses, but estimated 10,000 boulevard trees planted by the city will need replacement and thousands of residents will need to do extensive repair to their yards because of bad advice on letting their yards go dormant. Cost figures on landscaping losses in the cities will not be available until after the beginning of the next growing season when much additional damage will become evident.

4. Are we ready for a true water supply emergency in the metropolitan area? How long could we last without water from the Mississippi River?

**We are not ready for a serious water supply emergency in the metropolitan area. If an emergency existed, the means to withdraw water from the headwaters** reservoirs are not in place. The assumption has been that taking water from the reservoirs would be routine. But the events of 1988 showed us that tremendous pressure can prevent this. Additionally, water quality degradation does not seem to fit the Corps of Engineers' definition of "emergency situation." Therefore, release of water from the reservoirs to assist with wastewater assimilation apparently would not occur. Finally, Minneapolis is currently studying a water system backup, but a decision on how to proceed is still a year away. Until the backup system is in place, Minneapolis is at risk if its water intakes had to be closed for longer than one day.

**St. Paul Supply System**

Verne E. Jacobsen, Board of Water Commissioners, City of St. Paul, MN

The St. Paul Board of Water Commissioners was established by state law over 100 years ago. It exists to supply water for its 91,000 customers.

The board has four supply systems (see Figure 14):

1. The lake reservoir system
2. The Centerville - Rice Creek system
3. The Mississippi River
4. Groundwater wells

The City of St. Paul depends on the Mississippi River for about 70% of its water supply, but this water is not used directly. Instead it is pumped into a lake-reservoir system, which provides some storage capacity and buffers the water supply system from potential short-term disruptions in the river supply. With water restrictions in effect, the reservoir system can supply the City with water for about 45 days without taking water from the Mississippi River. However, this would cause the reservoirs to drop to unacceptably low levels. The remainder of the City's water supply is derived from the lake-reservoir system, including the Centerville-Rice Creek surface reservoir system (about 10%) and from groundwater wells (about 20%).

On June 30, 1988, the board held 4.9 billion gallons of water in the lake reservoir system. During low flow in the Mississippi River, the board limited withdrawals to 45 mgd. The board made shifts in available supply sources since the 1976 drought (see Tables 4 and 5). In 1976, the City of St. Paul obtained about 90% of its water from the Mississippi River. Development of a groundwater supply since that time reduced the City's dependency on the river by about 25%, and further development of groundwater sources is underway. The Board expects to add two or more wells in the near future.

Our customers' water demand remains unchanged and is expected to remain flat for the future. Unless major customers are added to the system, water demands will remain constant (Tables 6 and 7).

The board has been very conservative in developing raw water supplies to handle our customer needs. The utility has a supply system, a back-up supply system and is now building another back-up system. The board will continue to operate its supply system in the most responsible way possible during any crisis. However, the board expects to receive equal treatment from outside parties and that equal expectations for reserves shall be placed on all major users of the river.

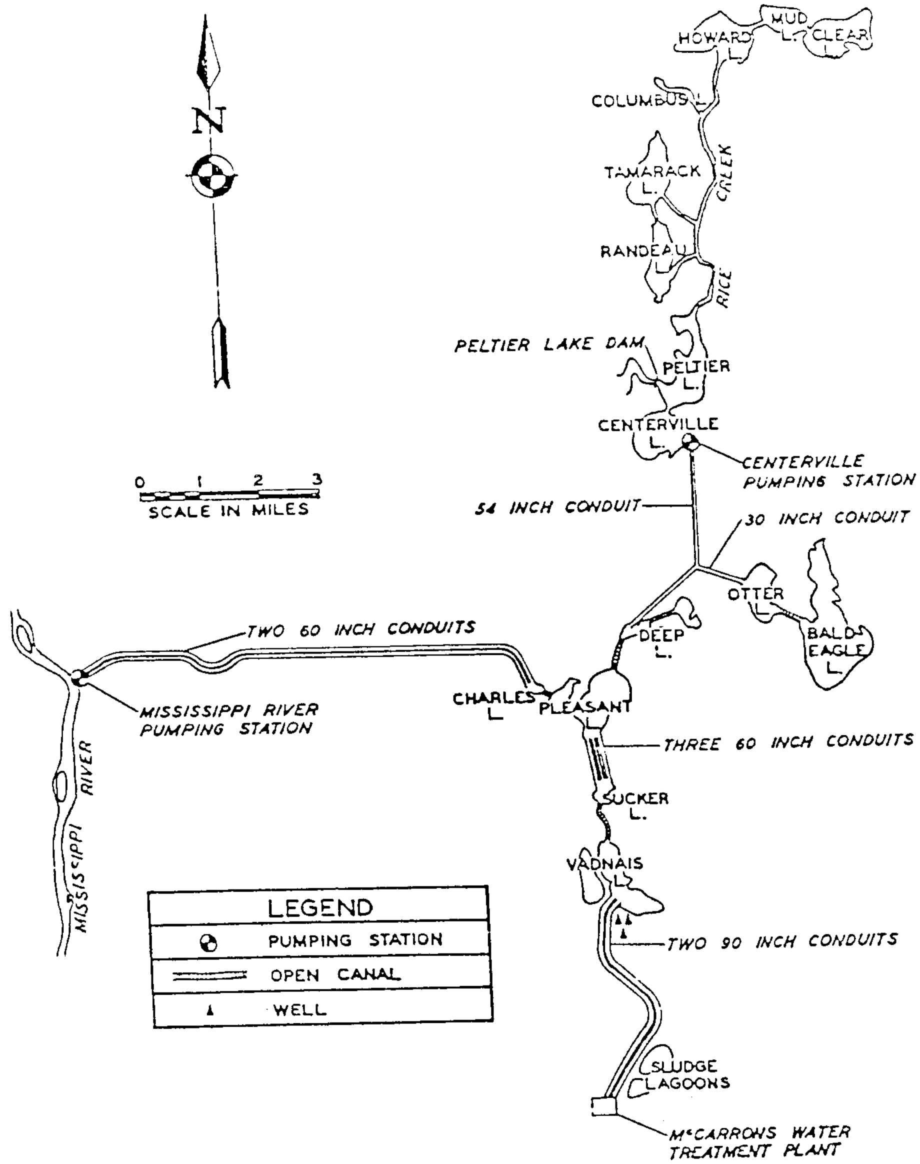
### 1988 Minneapolis Drought - Fact or Fancy

James Hayek, City of Minneapolis, Water Department

This is an overview of the problems that developed in Minneapolis as a result of the prolonged 1988 drought. To properly understand what happened, I will provide background information on the Minneapolis Water Works.

**History**. The Minneapolis Water Works began in the late 1860s as part of the fire protection system for mills on the south side of the Mississippi River. The first Minneapolis Water Works facility was a pumping station built in 1872 on property next door to what is now the Fuji-Ya Restaurant. The station took water directly from the Mississippi and pumped it into a distribution system. A similar facility was built soon after on the other side of the river on Hennepin Island.

Because of sewage contamination of the river and resulting disease problems, the pumping facilities were moved upstream to "cleaner" stretches of the Mississippi. Late in the 19th century, two pumping stations were built, one on each side of the river, at the Camden Bridge. Although they could pump directly into a distribution system on the west side of the river, they could also pump to a storage reservoir system in Columbia Heights. Because this did not resolve the disease problem, treatment facilities were built at the raw water storage basin




# SUPPLY SYSTEM

Figure 14

Table 4. Comparison of Water Supply Sources for St. Paul Water Utility in Two Drought Years, 1976 and 1988.

| | 1976 | | |
|---|---|---|---|
| | River | Centerville | Ground |
| June | 2064 | 0 | 0 |
| July | 2091 | 555 | 0 |
| August | 2089 | 16 | 0 |
| September | 1959 | 218 | 0 |
| Total | 8203 | 789 | 0 |
| Daily Average | 67.2 | 6.5 | 0 |
| % of Supply | 91.2 | 8.8 | 0 |

| | 1988 | | |
|---|---|---|---|
| | River | Centerville | Ground |
| June | 1956 | 33.5 | 533 |
| July | 1786 | 622.2 | 616.4 |
| August | 1647 | 13 | 578.7 |
| September | 1471 | 0 | 302.5 |
| Total | 6860 | 668.7 | 2030.6 |
| Daily Average | 56.2 | 5.5 | 16.6 |
| % of Supply | 71.8 | 7.0 | 21.2 |

Table 5. St. Paul Alternate Supply System, Centerville Station

| Year | Production, $10^6$ gallons/year |
|---|---|
| 1898 | 595.5 |
| 1899 | 1920.4 |
| 1900 | 1037.8 |
| 1901 | 1462.3 |
| 1902 | 2084.4 |
| 1903 | 309.4 |
| 1950 | 540.0 |
| 1969 | 2999.5 |
| 1976 | 4203.0 |
| 1988* | 1080 |

*Estimated for last 3 months

Table 6. Monthly and annual average values for daily water production by St. Paul Water Utility, 1969-1988.

Average Daily Consumption in Million Gallons Based on Pumpage

| Year | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Daily Average for Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1969 | 42.7 | 43.5 | 43.3 | 46.7 | 53.3 | 61.4 | 60.9 | 87.2 | 65.8 | 51.2 | 50.0 | 49.9 | 54.7 |
| 1970 | 50.6 | 50.7 | 49.8 | 50.9 | 53.5 | 69.8 | 81.2 | 67.8 | 53.4 | 46.3 | 46.6 | 43.4 | 55.1 |
| 1971 | 42.1 | 42.6 | 45.6 | 47.2 | 52.3 | 57.0 | 55.6 | 56.5 | 48.5 | 43.4 | 43.6 | 41.9 | 49.0 |
| 1972 | 42.3 | 42.7 | 44.0 | 43.2 | 55.6 | 60.8 | 54.3 | 57.8 | 48.3 | 45.4 | 43.8 | 43.9 | 48.5 |
| 1973 | 45.8 | 44.7 | 46.6 | 45.4 | 50.7 | 62.8 | 81.3 | 60.9 | 51.4 | 49.2 | 45.3 | 44.8 | 52.5 |
| 1974 | 44.6 | 44.3 | 46.0 | 48.3 | 49.0 | 57.6 | 82.0 | 66.1 | 55.3 | 50.4 | 46.1 | 45.5 | 53.0 |
| 1975 | 44.7 | 45.5 | 45.6 | 44.8 | 51.7 | 53.8 | 83.1 | 69.5 | 50.8 | 49.7 | 46.3 | 44.6 | 52.6 |
| 1976 | 44.4 | 45.3 | 52.2 | 49.5 | 66.3 | 76.6 | 88.1 | 77.5 | 57.1 | 48.3 | 46.5 | 45.3 | 57.6 |
| 1977 | 44.8 | 46.3 | 46.0 | 49.4 | 65.1 | 58.0 | 62.1 | 59.9 | 49.7 | 43.9 | 43.6 | 43.4 | 51.1 |
| 1978 | 43.8 | 44.4 | 44.3 | 44.2 | 55.4 | 55.4 | 57.8 | 67.0 | 54.0 | 49.1 | 46.6 | 46.0 | 50.6 |
| 1979 | 46.0 | 45.1 | 46.8 | 45.9 | 49.3 | 54.5 | 62.8 | 56.9 | 51.4 | 48.1 | 45.3 | 44.6 | 49.8 |
| 1980 | 44.7 | 45.0 | 45.6 | 49.7 | 65.1 | 59.1 | 82.0 | 57.0 | 52.8 | 48.8 | 58.1 | 46.2 | 53.8 |
| 1981 | 45.7 | 46.3 | 46.2 | 48.2 | 51.9 | 55.2 | 63.0 | 55.4 | 53.8 | 46.1 | 44.7 | 44.6 | 50.1 |
| 1982 | 44.3 | 45.8 | 45.9 | 44.8 | 48.6 | 60.8 | 76.1 | 76.8 | 52.3 | 47.2 | 45.7 | 43.2 | 52.7 |
| 1983 | 43.6 | 42.4 | 42.3 | 42.0 | 45.6 | 50.9 | 62.8 | 69.3 | 49.5 | 45.3 | 43.5 | 44.3 | 48.5 |
| 1984 | 44.9 | 43.0 | 43.2 | 44.6 | 47.4 | 56.7 | 68.4 | 60.0 | 50.3 | 47.7 | 45.0 | 43.4 | 49.6 |
| 1985 | 45.2 | 46.5 | 45.8 | 45.8 | 51.9 | 53.2 | 73.0 | 57.5 | 50.0 | 46.5 | 46.4 | 45.6 | 50.7 |
| 1986 | 48.7 | 46.2 | 47.1 | 46.7 | 51.7 | 67.1 | 59.8 | 56.1 | 48.5 | 46.9 | 45.0 | 44.8 | 50.8 |
| 1987 | 45.7 | 45.2 | 45.4 | 57.0 | 61.6 | 83.9 | 65.7 | 59.5 | 56.5 | 48.4 | 45.5 | 46.1 | 55.1 |
| 1988 | 46.4 | 46.7 | 46.8 | 49.3 | 64.8 | 94.8 | 82.4 | 63.1 | | | | | |

Table 7. Trends in Summertime Use of Mississippi River by St. Paul Water Utility

| | 1925 | 1934 | 1950 | 1969 | 1976 | 1988 |
|---|---|---|---|---|---|---|
| June | 562 | 947 | 1099 | 1827 | 2064 | 1956 |
| July | 862 | 880 | 1109 | 2053 | 2091 | 1786 |
| August | 896 | 748 | 974 | 2193 | 2089 | 1647 |
| September | 853 | 786 | 1203 | 2137 | 1959 | 1471 |
| Total | 3173 | 3361 | 4385 | 8210 | 8203 | 6860 |

in Columbia Heights. This first treatment facility for the Minneapolis Water Works included sand filtration and chlorination.

The final move upriver was made in 1926, when the present pumping and treatment facilities was built north of the Camden Bridge in Fridley, at 41st Avenue N.E. This treatment plant, as well as the one in Columbia Heights, still serve us today. Softening was added to the treatment process in 1941 at the Fridley plant complex, which is now the main treatment facility for the City of Minneapolis Water Works. Aside from the treatment facility and the raw water pump station, maintenance shops, a dewatering plant for treatment plant sludges, and the main finished water pumps are located at this site. Finished water is pumped to two large water mains that go beneath the river to the west side of the river and then into the city's water system.

**Geometry**. The City of Minneapolis is totally dependent on the Mississippi River as a source of water. In addition, the City has contracts to supply water to the following suburbs, which thus also are dependent on the river: Golden Valley, Crystal, New Hope, Columbia Heights, Hillside, and parts of Bloomington and Edina. The main pump station in the Fridley plant complex is built on the edge of the Mississippi River and is constructed of a series of rectangular chambers with openings to the river. The bottom of these basins is, in essence, the bottom of the Mississippi River. Bar racks and traveling screens take out floating debris. Water is withdrawn from these basins by a series of ten 36" diameter pipes near the bottom of the basin. At present, eight pipes are used to feed 20-and 30 million gallons per day (mgd) pumps, with a total capacity of 200 mgd. A pump station built in the late 19th century at the Camden Bridge is still in service and functions primarily to pump softened water from the softening plant to the treatment plant in Columbia Heights. The pump station also has intake structure screens, valves, and piping, and in an emergency it could withdraw water from the Mississippi River. Emergency use of the pumping station would be limited to a maximum of 80 mgd and it would bypass some of the normal treatment processes, such as softening, pH adjustment, and taste and odor control. The result would be water of poor quality, although it would be acceptable from a health standpoint. This pump station does have one advantage over the main pump station; its withdrawal pipes are located vertically and at a lower elevation, allowing water withdrawal at a lower level in the river.

Both pump stations are within the pool created by the weir and flashboards maintained for the NSP generating facilities at the St. Anthony Falls dam. The level of the river, which is determined by this weir, extends upstream beyond the main intake point for the Minneapolis Water Works. In fact, the top of the concrete of the weir on which the flashboards are mounted, determines an elevation above the intake point of our main pump station. The margin is not great, however, and vortexing might occur, which could upset withdrawals at that level. The flashboards, which are two feet high, give adequate depth at the main intake pump station. The weir structure creates a substantial reservoir in itself. If all external uses, such as lock operations, NSP power generation, and the St. Paul water utility were to stop withdrawing its 40 mgd from this reservoir, Minneapolis would have water for 23 days using the Camden pump station. This assumes that there would be no flow coming into the reservoir.

**The summer of 1988.** The summer of 1988 began with problems carried over from the previous year. In 1987, rainfall was marginal and little snow fell during the winter to build up soil moisture and supply runoff to the Mississippi River. As a result, the Minneapolis system had substantial water demand early in the year. Average consumption for May 1988 was 15% over May 1987. In the last ten days of May 1988, consumption averaged 122.2 mgd. Consumption over 100 mgd is considered high and it is unusual to have such a high consumption so early in the season. June consumption was even greater; the peak on June 6 was 175.71 mgd. Total June consumption for 1988 was 25% greater than 1987 which was a high water use year. It was 59% greater than June 1986, which was a normal year.

Daily consumption in early June was high enough that by the middle of June, water works managers were considering whether we should have some kind of sprinkling ban to ease the strain on the Minneapolis system. The June 6 peak was a strain on the treatment facilities and could not be sustained continuously. The consensus was that we had passed the peak and would be capable of handling the high but lesser amount of consumption in the middle of the month. Supply was never considered as a limiting factor in our ability to treat and deliver water.

By this time, members of the Governor's Drought Task Force had evaluated demand on the river and weather forecasts. They concluded that flow in the Mississippi was on a downward trend and probably would continue that way at least until the end of summer. By then, they felt there would be a water supply crisis at least for Minneapolis, if not for both Minneapolis and St. Paul. The Drought Task Force convinced the Minneapolis Public Works Engineer that the city should institute a water restriction program if the river reached a level of 1,000 cfs, as measured at the Anoka Dam.

It was understood that if the cities imposed a water restriction program, the DNR would recommend that the Corps of Engineers augment the Mississippi flow with water from the six headwater lakes to keep the Mississippi flow at the minimum level of 800 to 1,000 cfs. In addition, the implication was that the U.S. Corps of Engineers, who operate the dams on the upper lakes, would concur with this program.

As time went on, lobbying against this plan became very vocal. The Headwaters Association decried loss of income from decreased resort occupancy from "draining" of the lakes. The Leech Lake Indian Reservation argued that a lake level drop would destroy its rice crop. Finally, and most persuasive of all, the general public decried the "selfish" attitude of the city residents for sprinkling their lawns when farmers were suffering from the drought. The general public's perception, both in Minneapolis and outstate, was that the city was selfish and uncaring about the drought situation and that a sprinkling ban and other water restrictions should be imposed to ease this burden. The fact that water was going past our intakes to be lost forever, did not seem to affect this opinion. No one seemed to remember that we were talking about a flowing stream and not a fixed volume reservoir.

The city imposed an odd-even sprinkling ban in Minneapolis and suburbs that buy water from the city. In addition, people were asked to conserve water. The odd-even ban was imposed not as a conservation program but to ease people into a water cutback. At the time, water supply in the Mississippi did not require municipal water conservation.

In retrospect, the appeal for conservation probably was more influential in cutting back the demand than was the odd-even sprinkling ban. One elderly gentleman called me after the odd-even sprinkling ban was imposed on June 29 to ask me what the policy was in terms of birdbaths. He was quite concerned that there had been no mention of this in the conservation policy and that the birds would suffer because of a lack of water. I told him, of course, that this was not a significant use of water and that he should be sure to keep his birdbaths filled for the birds' benefit.

In any event, the result was a concerted effort on the part of many people to cut back on water usage because of the perceived water shortage. During the period of the odd-even ban (June 29 through July 26), average water consumption was 117.3 mgd. This is compared to the first 28 days of June, which averaged 148.9 mgd.

On Monday, July 25, the river had dropped to 800+ cfs. The Minneapolis Public Works Director called for a total ban on outdoor water use effective on July 27, as per the agreement with the DNR. The ban did have some exceptions. The Park Board had done substantial planting in their reforestation program, and these trees were at risk if they were not kept watered. Outdoor shrubs and gardens also were exceptions to the sprinkling ban. Golf course greens were given exceptions, which was very controversial. Many people complained about this exception because golf courses are perceived as for the "rich" whereas they, the "poor," were not allowed to sprinkle their lawns. There was even some controversy over whether children's wading pools should be permitted, and a great deal of time was spend discussing, with the weight going eventually to the side of permitting it. Decorative fountains were required to be shut down, although their water use is small since they function through recirculation of existing water. The fact was that the public looked upon this as a water use, and so they were requested to be shut down.

During the 21 days from July 27 through August 16 that we had the ban on the outdoor water use, consumption dropped to 82.7 mgd. This is a significant reduction from the average of 148.9 mgd in June, and considering the rather broad exceptions built into the sprinkling ban, a good example of what can be accomplished with broad coverage of the situation. Some people were anticipating that the cutback would result in winter consumption usage levels, but with the exceptions built into the system, this would have been unachievable.

The sprinkling ban was removed on August 17, after several substantial rains especially in the northern region of the watershed. It became obvious that the rains, coupled with the diminishing time before the Corps of Engineers starting dropping the reservoir levels for the winter, made a watering ban unnecessary. Despite the fact that the rainfall of the weekend before the end of the ban showed lines of equal precipitation in the watershed equalling 10 to 12 inches of rain, there was resistance on the part of resort owners to end the sprinkling ban. This was at a time when the levels of the lakes were at or above their normal summer operating levels. At one point during the meeting of the Drought Task Force, I suggested that perhaps Minneapolis and St. Paul could assist the resort area in flood prevention as a result of the rains. This tongue-in-cheek suggestion was not taken kindly.

Normally, the summer sprinkling season in Minneapolis ends around Labor Day and water consumption drops significantly after that. In that respect, 1988 has been unusual, as water consumption did not drop as much as normal after Labor Day. In some cases, the consumption levels have been over 100 mgd. I think this can be attributed to the fact that people were trying to restore their lawns by seeding and sodding, and the consequent use of water for that purpose increased demand over normal. Not all of the destruction of the lawns can be blamed on the sprinkling ban, for the dry spell was protracted and many people had ceased lawn watering prior to the ban. It goes without saying that substantial damage did result from the sprinkling ban.

Much was made of the loss in revenue to the Resort Owners Association, as well as to the Indians and their wild rice crop; but little has been said about the loss to the citizens of the City of Minneapolis and their lawns. I believe that what the citizens of Minneapolis lost in lawns exceeds many times the value of the perceived losses by the two strong lobbying associations in upper Minnesota. While I am not a "lawn" person, I do sympathize with many people in the City of Minneapolis who saw a cherished possession destroyed this summer. We certainly are not comparing the plight of the farmers during the drought with the loss of someone's lawn, if there were any relationship between the two, which of course there is not. I am saying that the citizens of Minneapolis suffered a severe economic loss through actions which are, at best, debatable.

**Part IV - Planning for a drought and a water emergency.** Much has been made of the fact that Minneapolis has a single source of water, that being a rather vulnerable surface supply, namely, the Mississippi River. The last previous drought experience was in 1977. At that time, we experienced similar problems with the flow level of the Mississippi River, although it started later in the season. It was the first instance of a drought situation since the 1930's, and so we did find out that no one knew anything about what was happening or who was responsible for what, or what should be done. It was a period of great confusion, which we muddled through successfully without incident, although there are still rumors of water levels dropping below the intakes at the Mississippi pumping station still circulating. What we did find out for sure at that time was that there was severe antagonism and resistance to augmenting the Mississippi River for the benefit of the Cities of Minneapolis and St. Paul. This was despite the fact that neither Minneapolis nor St. Paul had requested any augmentation from these lakes.

In any event, the situation precipitated research into the alternatives for a secondary source to supply water during an emergency or during extended drought periods. Most of the various alternatives were discarded as being unobtainable such as, for example, the suggestion that we take water from Lake Superior. They were unobtainable because they were politically impossible to achieve or were extremely expensive or suffered the same problems as the surface source that we were using; that is, they were subject to the same conditions that created the drought flow conditions in the Mississippi.

The one system that did seem viable was to drill a series of shallow wells (100 to 110 feet) deep and withdraw water from this aquifer. Our design parameters for the amount of waters needed to supply the City of Minneapolis was a minimum of 50 million gallons per day. This was estimated based on achievable water conservation by banning external water usage for sprinkling and other outdoor activities, coupled with an intense public appeal for curtailment of consumption.

With this volume in mind, it was obvious to us that a few deep wells would not be adequate to supply that volume. We had a consultant do a study in 1978 of the shallow aquifer supply situation in our plant area, which is bounded by 37th Avenue on the south, about 48th Avenue N.E. on the north, the East River Road and Mississippi River on the two sides. Unfortunately, the study showed that this area was isolated on the east and south by impermeable layers and the recharge was not adequate to sustain the amount desired. The maximum that could be obtained from the area was about 14 mgd. As a consequence, we budgeted for an expanded study involving land north of our property, which at that time was owned by the FMC Corporation and is now a part of the Anoka County Park system.

Before the study could be done, the issue of underground contamination emerged in December 1981. Because the contamination involved the same aquifer that we were studying as a source, we delayed our investigation until resolution of the contamination problem. Unfortunately, aquifer cleanup did not begin until December 1987, and the cleanup will take a minimum of five years and probably will take ten years to achieve a 99.9% removal. Even 99.9% removal will leave the aquifer unsuitable for potable water use. Therefore, if t[he water is to be used for potable water supply, it would have to be coupled with an expensive granulated activated carbon (GAC) treatment facility.

While waiting for the FMC aquifer cleanup to occur, we considered a plan of using a combination of deep wells and shallow aquifer wells to get the necessary amount of water. We know that deep wells alone would require an area of land far larger than we could acquire, but with the two systems together, we could perhaps achieve our goal.

To this end, we engaged with the USGS in a jointly-funded three-year study of the northern metro area. The goal was to determine the interrelationship of lakes, streams and the Mississippi River with the shallow and deep aquifers. This information will provide some design parameters for a system of shallow and deep wells that would have the least impact on the total water systems in the metro area, yet give Minneapolis the desired volume for a standby water supply. The USGS study ends in October 1989. We hope that when the report is received, some decisions can be made about the future of the Minneapolis water supply.

**Water Requirements for NSP Minnesota Thermoelectric Generating Plants**

David Heberling, Northern States Power, Minneapolis, MN

NSP's power plants are located on Minnesota's major river systems - the Mississippi, Minnesota and St. Croix Rivers (Figure 15), and water use characteristics of the plants are summarized in Table 8. The primary focus on water use and electrical generation during the 1988 drought was on NSP plants along the Mississippi River (Monticello and Sherco) upstream from the Twin Cities. These two power plants account for roughly half of NSP's base load generating system.

NSP thermoelectric power plants are as dependent upon cooling water as they are on fuel for generating electricity. Surface water use by NSP power plants is primarily for noncontact cooling purposes. Although these plants withdraw large quantities of water for cooling, their consumptive rates are low (see Table 8). Consumptive use rates are dictated by the type of cooling mode employed by the plant. An open-cycle plant, where water is pumped through the condenser and discharged directly back to the water source, consumes very little water. Plants that operate in either helper-cycle modes (where water is pumped through cooling towers prior to being discharged) or closed-cycle modes (where water is reused for cooling after being run through cooling towers) consume more water than open-cycle plants because of evaporative losses in the cooling towers. Except for Sherco, which operates closed-cycle year-round (Figure 16), NSP plants operate in helper or closed-cycle cooling modes only during the summer months.

Power plants can be operationally limited by both physical and regulatory cooling water constraints. From a physical standpoint, plants such as Monticello and Sherco, whose intakes are not in a regulated pool environment are dependent upon river flow to provide adequate water elevation for pump intakes. For both Monticello and Sherco, the critical flow that provides the needed intake elevation is about 200 to 250 cfs. Other parameters that may affect plant generation by reducing condenser efficiency are water temperature and quality.

Power plants also have regulatory constraints for both water appropriation and discharge. The Monticello Plant is allowed to appropriate up to 645 cfs, but it cannot withdraw more than 75% of the river flow (Figure 17). When river flows drop below 860 cfs, the plant must begin to recirculate a portion of the cooling tower discharge water to the condenser. The plant has seasonal discharge temperature limits that can also restrict the amount of condenser cooling and, consequently generation. The combined physical and regulatory water use constraints during the 1988 drought at times caused the Monticello Plant to be limited to 70% of its generating capacity.

The generation loss at Monticello (up to 160 Mw -- enough electricity to serve 160,000 homes) occurred during a time of peak system demand. A major portion of this peak demand was air conditioning, with cooling degree requirements running 174% of normal during the 1988 summer months (Figure 18). The peak NSP system demand of 6903 Mw occurred on August 16, 1988. During this peak demand, power purchases constituted approximately 25% of the electrical service to NSP customers (Figure 19). It is estimated that replacement power purchases for each week that Monticello was limited to 75% power cost the average NSP residential customer an additional $0.07 to $0.09. Although the 1988 drought resulted in generating limitations for NSP facilities, service to NSP customers was never jeopardized because of a combination of system generation and power purchases. While the extent of the 1988 limitations to NSP generating facilities was tolerable, any condition, whether physical or regulatory, that would cause the loss of the entire generation capacity of both Monticello and Sherco under 1988 peak demand conditions would create power shortages for customers. They could also cause severe electrical equipment damage to the NSP system and the entire Mid-Continent Area Power Pool (MAPP).

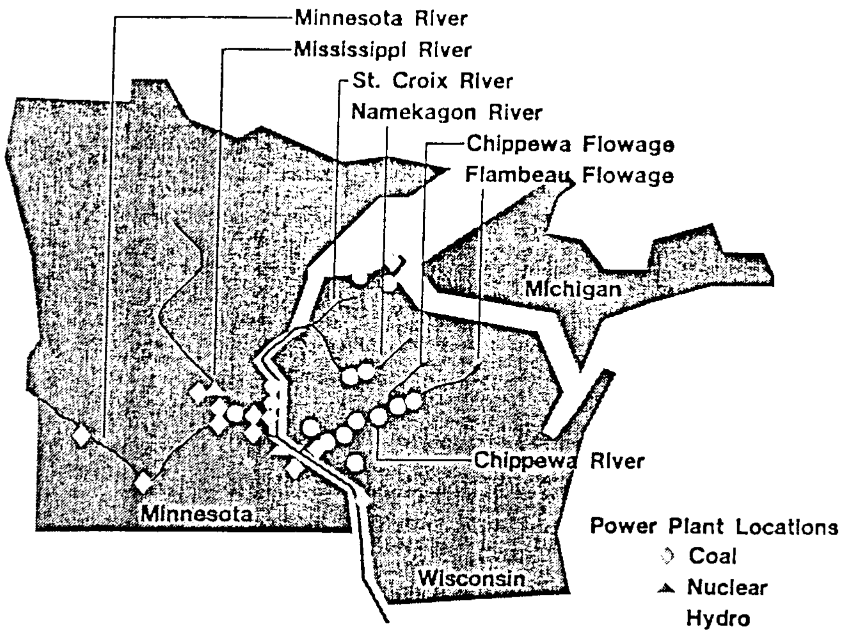



Figure 15. NSP Power Plant Location

Table 8. NSP Minnesota Thermoelectric Power Plant Surface Water Use Rates

| Appropriation Plant | Generating Capacity (Mw) | Summer Cooling Mode | Maximum Consumpt. Use (cfs) | Permit Limit (cfs) |
|---|---|---|---|---|
| Miss. R. above TC | | | | |
| Intakes | | | | |
| Sherco (Becker) | 2200 | Closed | 47 | 67[1] |
| Monticello | 547 | Helper | 10 | 645 |
| Miss. R. below TC | | | | |
| Intakes | | | | |
| Riverside (Mpls) | 326 | Open | 1 | 543[2] |
| High Bridge (St. Paul) | 360 | Open | 1 | 490[1] |
| Prairie Island (Red Wing) | 1064 | Closed | 30 | 1360 |
| Red Wing | 24 | Open | <1 | 84[1] |
| Minnesota River | | | | |
| Minnesota Valley (Granite Falls) | 47 | Open | <1 | 118[1] |
| Wilmarth (Mankato) | 20 | Open | <1 | 51[1] |
| Black Dog (Burnsville) | 443 | Open | 1 | 633[2] |
| St. Croix River | | | | |
| King (Oak Park Heights) | 571 | Helper | 14 | 660 |

[1] Converted from gpm limit
[2] Converted from acre-feet per year limit

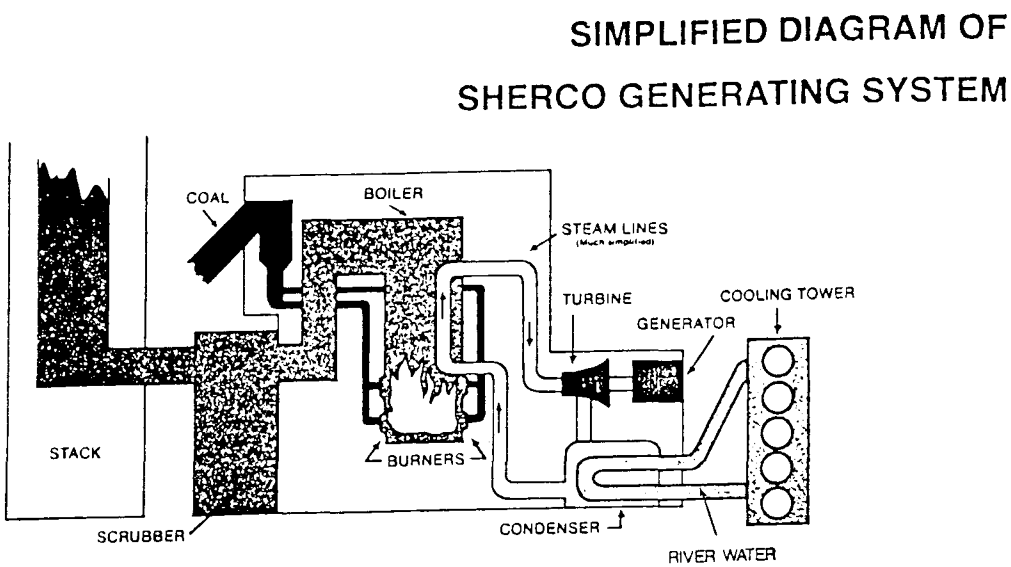



Figure 16. Sherco generating system

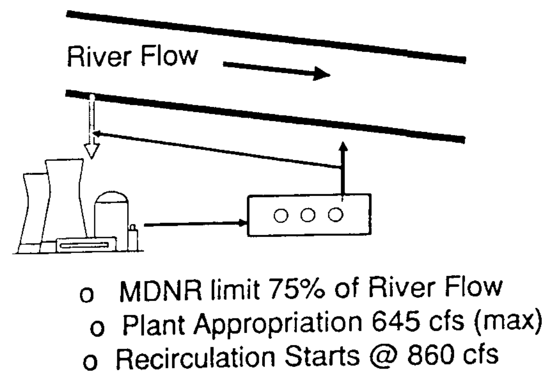



Figure 17. Appropriation limits



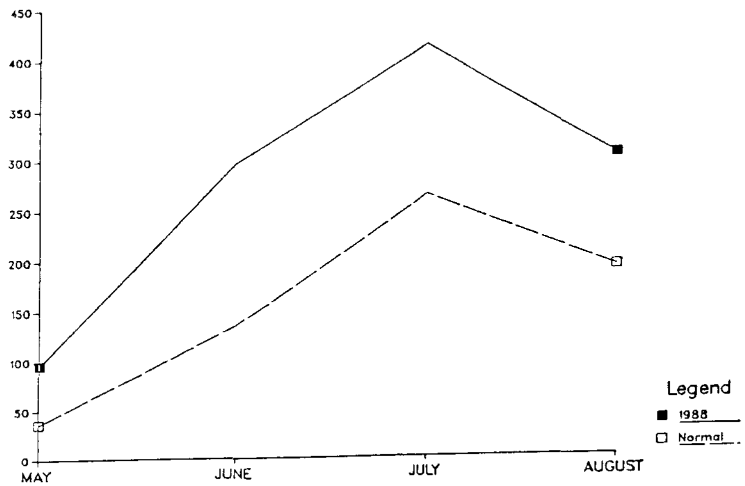



Figure 18. 1988 cooling degree days vs normal

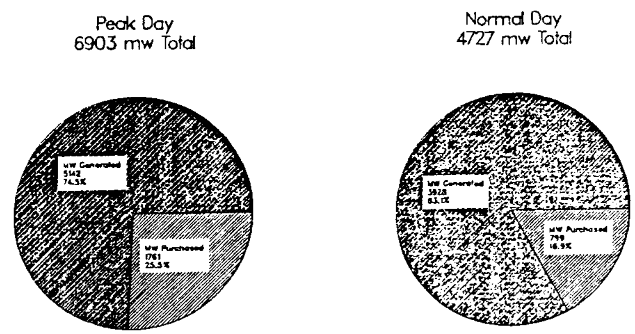



Figure 19. Meeting the demand

**Water Quality Issues Regarding the Mississippi River in the Metropolitan Twin Cities Area During the 1988 Drought**

Donald R. Madore, Metropolitan Waste Control Commission, St. Paul, MN

The Metropolitan Waste Control Commission (MWCC) is a public service agency dedicated to the efficient treatment of wastewater in full compliance with environmental standards. The primary receiving waters for MWCC facility discharges are the Mississippi and Minnesota Rivers. The MWCC routinely monitors the rivers to determine water quality above and below facility discharge points. This monitoring includes conventional parameters, such as dissolved oxygen; toxics, such as heavy metals; and direct toxicity evaluations. Information from routine monitoring and historical records is used by the Minnesota Pollution Control Agency (MPCA) to determine discharge limits for MWCC and other facilities that will maintain receiving water quality. Current permit limits are based on a summer river flow of 1703 cfs as a once in a ten year flow with a seven day duration (7Q10).

The summer of 1988 produced drought conditions with river flows substantially below 7Q10 flows. The drought provided a natural test of the impact of metro area discharges on the rivers. The MWCC combined optimal operation, expanded routine monitoring, and added intensive surveys in an effort to minimize the impacts of discharges and evaluate the water quality of the rivers under extreme conditions.

The MWCC maintained discharges that met permit limits and often improved on the permitted degree of treatment by 50 to 70%. The metro plant chlorination/dechlorination facility effectively removed residual chlorine to prevent toxicity to aquatic organisms in the river. Effluent aeration was maintained from June 2 through October 7 to ensure an adequate effluent dissolved oxygen (D0) level (8 mg/L). The effluent aeration was triggered by low upstream and downstream river DO levels.

From June 17 through July 1, the MWCC and the MPCA conducted an intensive Mississippi River survey to assess the immediate drought impacts and to verify computer modeling predictions. Dissolved oxygen levels were found to be at or above applicable standards downstream of the metro plant during the survey period, but upstream DO levels did not meet the standard at all times. Concentrations of metals in the river did not exceed applicable standards or guidelines.

River monitoring conducted through July and August reinforced the conclusions of the intensive survey. July 8 marked the lowest river flow at St. Paul (752 cfs). On this day, DO levels did not meet the standard upstream of Metro Plant but were in compliance downstream of the plant. The Minnesota River continued to show the effects of nonpoint source loadings throughout the summer and DO standard violations were common in this basin.

The MWCC is limited to use of the river as a receiving water and the Commission has a responsibility to maintain water quality of receiving waters. Based on experience of this summer, the drinking water intake requirements for Minneapolis would limit river water withdrawals before waste disposal needs would.

## Panel IV: UPSTREAM USER INTERESTS

### CHAIR: Molly MacGregor

**Issues Statement**

This panel examined opposition in northern Minnesota to use of supplemental water from the headwaters lakes of the Mississippi River for the Twin Cities' area water supply. Represented on the panel were local government, Indian tribal leadership, the resort industry, and the academic community.

The issues were political, social, and cultural; such issues have become familiar stumbling blocks in the political process. The panel concluded with a call to include consideration of these issues in decision-making about natural resources management.

Residents in northern Minnesota criticized the state's lack of long-range planning, the crisis mentality of the drawdown plan, and the use of language that heightened the perceived losses of a proposed drawdown. They also criticized the lack of a meaningful role for northern Minnesota in the decision-making process, despite the potential perceived impact on the region. Local governments became a focus for this criticism, and county boards passed resolutions opposing additional releases unless the Twin Cities adopted strict water conservation measures. Local governments worked with legislators to host public informational meetings.

Criticism of the state's drought plan was linked to a history of division between rural and urban Minnesota. The northern area resources are significant to the state's economy, but residents of the region believe they lacks the political resources to assert their independence against the more populous metropolitan area.

Two Indian bands, the Leech Lake and Sandy Lake Bands, expressed similar criticism of the state's proposal to release additional water from the headwaters reservoirs to the U.S. Corps of Engineers. The bands cited the United State's trust relationship with Indian tribes, the negative effect of water releases on tribal resources, especially wild rice and trapping, and the history of exploitation of Indian bands by the government.

The resort industry is a significant economic resource for the state and the region. This research-based industry has flourished because of the region's abundant water. The lack of water could impair or destroy visitors' expectations for a true northern Minnesota vacation. The language of media reports on the drought task force suggested that area lakes could literally dry up. This created concern and some cancellations among scheduled tourists.

From an observer's point of view, reactions to the drought of 1988 appeared on three levels -- the adaptive or gut response, which may include water hoarding; the social level where issues of equity are addressed and the cultural level, where lifestyles -- such as those promoting development of green lawns and frequent car washing -- are criticized. Popular perceptions should be included in the decision-making process, although those perceptions typically are discounted in management and allocation of natural resources allocation issues.

### Perspectives of the Mississippi Headwaters Board

Molly MacGregor, Mississippi Headwaters Board, Walker, MN

Local government in northern Minnesota responded quickly when the news media reported that the state was proposing an additional release from headwaters reservoirs to supplement low flows in the Mississippi River at the Twin Cities. County boards of commissioners of four counties with reservoirs (Cass, Itasca, Aitkin, and Crow Wing) passed resolutions opposing additional releases without strict conservation measures imposed on Twin Cities water users. Those resolutions favored additional releases in the event of emergency or threat to human health and safety.

Local governments sponsored three public informational meetings with representatives of the U.S. Army Corps of Engineers, the Minnesota DNR and the Minnesota Office of Tourism.

In addition to opposing the release plan itself, local governments objected to:

* Language used by the news media and state officials to describe the Headwaters area and the effect of the proposed plan;
* Lack of credibility of base flow rates and trigger rates established by a state drought task force to monitor low flows on the Mississippi River in the metropolitan area;
* Lack of consideration of regional issues by the state in the drought planning process;
* Lack of representation by local government from the headwaters region on the state's drought planning task force;
* Lack of long-range planning by the state and the city of Minneapolis, despite similar crises in 1976 and 1961.

Media coverage, generated in large part from the metropolitan area, used language that minimized the impact and misinterpreted the effect of a drawdown on the headwaters area. For example, the first reports on the proposed additional release said the state "would drain six northern Minnesota lakes." Despite efforts by state officials to correct this impression, the damage was done. Another media source stated that a proposed release would result in a 16 inch loss of water to a lake, whereas the actual was about a quarter of the reported amount.

The media reported that the reservoirs were man-made lakes, although in reality, construction of dams at the outlets of the lakes by the Corps 100 to 75 years ago simply raised levels of existing lakes from two to eleven feet. Insisting that the reservoirs were not natural lakes suggested that the issues of equity raised by northern Minnesota resorters were unreasonable. If the lakes were not natural in origin, how could resorters and other property owners complain about use of the water outside the lake basin, the argument suggested?

The state's drought task force proposed a base rate of flow for the Mississippi River of 1,000 cfs and a trigger point of 800 cfs in Anoka. At that point, additional releases would be requested to supplement flows within three weeks at the Twin Cities. Northern Minnesotans criticized the validity of these numbers as political compromises based on anticipated needs by users in the metropolitan area, rather than solid evidence or knowledge of in-stream needs. Later events substantiated the argument that the base rate and trigger points were not "solid" numbers. The numbers were established by state officials without consideration of in-stream flow needs in the headwaters area or the impact of dams and control structures between the headwaters and the Twin Cities.

Local governments in northern Minnesota requested representation in the decision-making process (local businesses were so represented). The state eventually chose the Mississippi Headwaters Board (MHB) as a designated representative. The MHB is an eight county joint powers board charged with protecting and conserving the first 400 miles of the Mississippi River. The primary tool for achieving those objectives is administration of a shoreland zoning ordinance. The MHB also is charged with planning for the area under its jurisdiction and has been coordinating meetings of dam operators on the Mississippi River between Bemidji and Grand Rapids for several years. Review and update of the operating plan of the reservoirs has been a priority issue for the MHB.

Minnesota droughts have resulted in low-flow crises in the Twin Cities at least three times in the last 25 years. Northern Minnesota residents support an alternative water supply and drought planning for the Twin Cities. Although the headwaters area is generally water-rich, it is also dependent on abundant surface waters. Drought plans that include releases of additional water from the headwaters will always be politically unpopular if those releases are not part of an overall drought management strategy.

### Resort and Tourism Industry Perspective

Roger Schwieters, Minnesota Resort Congress, Cross Lake, MN

Minnesota's resort industry has grown to become potentially the state's number one industry, generating $6 billion in business in 1985. In northern Minnesota, it is the largest industry. The waters of northern Minnesota are the foundation of that industry. Resorts, summer shoreland residents, and ancillary businesses all exist because the water is there. The presence of water creates the tourism industry; without it the perceived value of a northern Minnesota vacation does not exist. In one township, 60 percent of the surface is water and 40% is land. The abundance of water in the township supports 23 resorts, hundreds of shoreland residents, and numerous support businesses.

## The Social and Cultural Shaping of the Drought of 1988

Luther Gerlach, Professor of Anthropology and Adjunct Professor of Public Affairs, University of Minnesota

*Introduction - The established approach to environmental resource management*

Decision-makers in Minnesota approached problems of water supply during the 1987-88 drought much as decision-makers in western industrial societies approach most environmental and resource management problems. This established approach to problems has been well documented and endorsed (NRC 1983). In this approach to risk assessment and management, specialists seek to distinguish between the "real" and the "perceived" problems or risks (Freudenberg 1988). Those problems considered to be real usually concern biophysical, economic, and technological factors. Specialists assess these "real problems" and delineate the benefits and costs of various courses of action to manage the problems. From this, leaders can select the most appropriate course.

Leaders expect to exercise political will to regulate established technologies of water use and supply. They seek public support for their decisions by showing that they listen to competing interest groups. They might ration use of the resource because of shortages or to demonstrate fairness. But they usually accept the growth premises of conventional American culture (Gerlach 1977, Milbrath 1984) and define the problem of assuring adequate long term resource supply as one of increasing the availability and reliability of the resource to meet expanding demand, and not one of reducing the demand by institutionalizing conservation. This established approach continues to dominate decision-making, but the process often does not run smoothly. People bring the complicating factors of social action and cultural interpretation into environmental decision-making (Johnson and Covello, 1987). Thus, even though specialists may say that resource management decisions are ecologically sound, economically viable, and technologically feasible, they may find these decisions are not politically practical or socially acceptable (Gerlach 1987, Gerlach and Meiller 1987). This poses difficulties for decision-makers, but there are remedies.

Remedies. I suggest that in learning more about how people push and pull social and cultural factors into the decision-making arena, political leaders and the technical specialists who advise them can learn more about how their own expert judgments are shaped by social forces and cultural biases. By thinking more *objectively* about how they *subjectively* screen and interpret data, they will better understand and deal with the public's subjectivity. As decision-makers learn more about these factors they will improve their ability to incorporate them into the decision-making process and make this process more holistic and disciplinary.

Opportunities. When decision-makers pay attention to the social and cultural dimensions of resource management they can discover a rich source of information about the broader concerns of the public and recognize opportunities for constructive socio-cultural change. People's social concerns and cultural biases provide a forum to dramatize and work out social and cultural problems, explore paths to change, and build the social consensus to take some of these paths. Natural resources are not simply a tangible object but rather involve a functional relationship between cultural values and social means of manipulating the biophysical environment (O'Riordan 1971). Controversies over natural resources are about these values and means, and often about deeper and broader values and social relationships. It is in search of knowledge about cultural and social values that we can look at the problems of water supply during and after the drought of 1988.

*Quarreling over water and shaping interpretations of the problem: the Minnesota case.*

During the drought of 1988, Minnesotans quarreled over water supply. Most dramatically, they quarreled over whether the headwaters of the Mississippi River should be drawn down to augment river flow. They disagreed over whether the augmentation was required to protect aquatic life and to meet the water supply needs of Minneapolis and St. Paul. They disputed the impact of the drawdown on the headwaters lakes and those using them. They disputed the uses to which city people put the water, and the physical and political reasons for imposing controls on such use. They argued over how decisions were being made to manage water, and who should be involved in making these decisions. They quarreled about all of this and much more, so that officials made wry references to the quote attributed to Mark Twain, that "whiskey is for drinking, water is for fighting."

That Minnesotans and people across the country quarreled over water during the drought is a fact. It is a social and cultural fact which contained few surprises. The controversies followed a regular and predictable pattern of social action and cultural interpretation. That is, the events were regular and predictable if one examined them using findings and models drawn from the study of other resource management controversies. It is also a fact that people involved in water management controversies try to define the legitimate parts of the process through which the controversies are handled and the problems of water supply are solved. Since the controversy is about the management of a natural resource -- water -- specialists in biological, physical, technological, economic, and legal aspects of water play a major role. They claim, and others appear to agree, that "the facts" should predominate in decision-making.

Reluctantly, specialists and the leaders they advise admit that other factors also affect making and implementing decisions. These factors may be called "more amorphous" or "perceived risks." Most regard them as intrusions, that confuse or interfere with otherwise rational problem solving.

Political Constraints and Sociocultural factors.

Specialists may recognize some of these factors as "political constraints", factors which may escape technical control but which political leaders can identify and deal with by making certain exchanges. But decision-makers are likely to be distressed by the presence of broader and deeper social and cultural factors. Such factors include long histories of tension between the disputants, popular beliefs about the risks and equities of competing uses of water, the symbolic significance of such uses, and the media coverage of these factors.

Some examples of these factors during the drought: some people defined the headwaters lakes as natural and pure, and considered it wrong to use such water to dilute urban sewage. Other people argued over whether the headwaters lakes were carved out naturally by the glaciers or were built by humans as a "reservoir." People disagreed over whether watering lawns and golf courses or washing cars was frivolous or an economically justifiable activity, and whether releasing water from the headwaters lakes to meet city needs was an unnecessary sacrifice or an act of responsible cooperation. People were sensitive to the word "drain" to describe taking water from the headwaters system, particularly when this term was reportedly first used by a television station based in the Twin Cities, which recently had bought a headwaters area station.

Leaders must find ways to incorporate these broader social and cultural factors to their decision-making prowess rather than discounting them as emotional and irrational. As a first step, leaders should recognize that these social and cultural factors are "real," that they affect outcomes, that they are patterned or regular in their development and impact, and that much of this development and impact can be predicted. This does not mean that these factors can be controlled (in the sense of controlling biophysical phenomena). Controlling social and cultural factors means controlling people in ways which are likely to be repugnant to most Americans. If Americans are to change their ways, they must be involved in making the decisions to implement (or reject) change. They must be persuaded or educated to change, not commanded to do so. In the process, people are likely to change the agents and patterns of change, even as they modify their own ways of interpreting and dealing with the environment and the world.

*Decision-makers are also socioculturally subjective.*

It is important that decision-makers recognize they cannot presume to work independently of social pressures and cultural interpretations. Decision-makers will share with other members of their groups beliefs about what facts are important, what risks are real versus perceived, and what constitutes evidence for decision-making (Coppack 1984; Douglas and Wildavsky 1982; Rayner 1988). They will reinforce these beliefs in their interaction with other members of the groups.

For example, information about water quantity and quality is central to decisions about management of the Mississippi River. Most participants in the decision-making process will probably share the dominant American cultural belief that to assure adequate long-range water supplies, we should increase supply, not reduce consumption through conservation. While government and industrial users of the river focus on flow rate problems, residents of the headwaters area are more concerned about the depth of water in the headwaters lakes.

Further, it seems that each group disagrees on what river flow rates are necessary to meet user needs. Each of these constituencies has its own interpretation of appropriate users and needs. This interpretation reflects not only material interests but more deeply-seated bias, that of their particular research and/or decision-making subculture. For example, we expect that biologists interested in protecting aquatic life will assess the requirements of river flow from a different perspective than officials concerned with assimilating urban sewage. People interested primarily in maintaining headwaters lake levels will assess these requirements differently than those concerned with urban water uses. Similarly, officials representing Minneapolis, which relies solely on the Mississippi River for water, will have a different perspective than those representing St. Paul, which draws water from two major alternative sources.

In short, decision-makers in Minnesota during to the drought of 1988 are like decision-makers everywhere. They are part of the sociocultural system, not apart from it. It would be useful for them to think through the social pressures and cultural biases that affect their interpretation of problems and solutions. From this, they will gain a better understanding of the social and cultural forces that affect the responses of the public.

*Parables, plays, and prayers of the drought of 1988*

Water is for fighting, but its also for thinking. Because of the drought, Minnesotans did fight over water, but more importantly they thought about this resource, about their use and management of it, about their social interrelationships, and even about their ways of life and cultural futures. In doing this, people used symbols. They expressed the drought symbolically. They loaded onto drought and water issues a variety of other issues, again often symbolically. This process of elaboration has complicated the process of decision-making. But the process also offers people an opportunity to deal creatively with a variety of deep seated problems, from building resilience into water supply systems, to healing social tensions, and exploring pathways to culture change. We can identify three dimensions to this process: basic adjustment, social statement, and cultural questioning (Gerlach and Whitaker 1989).

**Basic Adjustment.** Immediate responses to the drought involved basic efforts to adjust to its impacts through individual effort, competition, and cooperation. Some specialists defined the drought as a short term event to which humans could adjust but which they could not prevent. From this perspective, it was no one's "fault" if people suffered material losses from the drought. People should not be blamed, but rather given sympathy, counseling, immediate relief, and compensation. In their basic responses to the drought, people defended themselves against its material and psychological impacts, and where possible, found some advantage or silver lining in it. Some nervously watched weather reports, called to the heavens or prayed for rain, sought assistance, drought insurance, and the like. Some quickly horded food and tried to get their share of water before it was too late. Some raised prices on a variety of products, bid on commodity futures, or simply enjoyed the sun. Television stations and newspapers had newsworthy topics, political leaders had new avenues to win over voters, and the Department of Transportation found the weather good for road building.

**Social Relationships.** As the drought progressed and water supply became an issue, people soon began to relate water use to their relationships with each other. For example, while suburban neighbors fought over who watered the lawn or washed the car, farmers who were ordered not to irrigate resented city people who continued to water their lawns. Car washing and lawn and golf course sprinkling became ways to talk about social equity and fairness. If some people cut back and let their lawns turn brown, why shouldn't everyone? Was it true that some people were sneaking out and watering their lawns at night? Can the Cities really order northern residents to release some of their water? The disputes and complaints were reported and debated in the news. A newspaper editorialist wrote about how "neighborly spirits wither in a dry time".

When the proposal was made to release water from headwaters lakes the response from people living near the headwaters was hostile. Some of the hostility reflected immediate concerns. Resort owners complained they would lose business when people heard that the lakes would be "drained." They worried that boats would not be able to get through shallow channels or that boat propellers would be broken. Native Americans worried that their wild rice crop would be damaged and that serious problems would occur in harvesting the crop. They pointed to the symbolic as well as the nutritional and economic importance of wild rice.

Native Americans, resort owners, and other northern Minnesotans raised the question of equity. They said that while they would send water to the Cities if it were really needed, they objected to having their lakes "sacrificed" to the Cities, which seemed to be wasting water. Like some people in the Cities, they interpreted as misuse the use of water to water lawns and golf courses, to wash cars, and to dilute urban sewage. Some talked about residents of the cities as if they all live in affluent suburbs and drive luxury vehicles. They directed their attention chiefly to Minneapolis, since (unlike St. Paul) the city has no backup water supply despite concerns raised during a serious drought in 1976.

Minneapolis officials explained that the costs of losing lawns and the urban forest to watering bans far exceeded costs in the headwaters area of drawing down some of the headwaters lakes. It mattered not. The issue went far deeper than comparative economic cost and benefit and the physics of water flow. It reflected a long social history of ambivalent and sometimes tense relationships between "the Cities" and northerners, and between Native Americans and others. Similarly, though perhaps to a lesser extent, the controversies over water supply reflect long standing rivalries between Minneapolis and St. Paul. I will not attempt at this point to discuss these histories and tensions. I will simply point out that the drought and water supply problems provided a setting where people could debate these, and perhaps find avenues of change and resolution.

**Cultural Critique.** Northerners and city people have engaged in a broad cultural critique, using the drought and water supply as a stage. Some have argued against lawn-sprinkling as one example of the excesses of city life, rather than as a matter of fairness and sharing limited resources. They attack the idea of having lawns in the first place. Lawns, they say, are symbols of false values, a middle-class simulation of the ostentatious gardens and lawns of the Victorian era. They decry the use of pesticides and fertilizers as threats to public health. One writer looks forward to a post-drought landscape of "natural things," and even front yard food gardens. Similarly, debating the causes and implications of the predicted greenhouse effect, which some people have connected to the drought, has provided a symbolic framework for thinking about the relationship between humans and nature. Some religious leaders caution people that the drought and the greenhouse effect do more than challenge them to respond through science or even good stewardship. People also should consider both their vulnerability and the blessings they take for granted. Yet other clergy warn that perhaps the Earth, through the drought or the greenhouse effect, is showing people it cannot sustain their abuses, either material or moral. One minister used a Biblical example to say that when people don't live well together, the Earth withers in drought.

In short, even as some people were defining the drought as natural and uncontrollable, others were defining it as a product of human actions. About as soon as North Americans began to suffer badly from the drought and to worry about their future, some, maybe many, turned to the supernatural and prayed for rain. Some worried that the drought was a sign from God that they had indeed sinned, whether in their treatment of the environment, their treatment of other people, or their quest for material gain over spiritual, environmental, or social values. What does this do to attempts to hold tough decision making within the confines of the real facts and the hard numbers?

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## Mississippi Headwaters and Related Resource Use of the Leech Lake Band of Chippewa Indians

Joseph H. Shepherd, Acting Director, Division of Resource Management, Leech Lake Reservation Business Committee.

**Introduction**. The Leech Lake Indian Reservation, located in northcentral Minnesota, was reserved by the Leech Lake Band of Chippewa by treaty with the U.S. Government in 1855. It continues under modifying provisions of subsequent treaties and executive orders.

The reservation is comprised of approximately 588,684 acres of forest, wetlands, and natural lakes and flowages. The northern most reaches of the Mississippi River traverse the reservation from west to east through a series of large scenic lakes. The southern area of the reservation is dominated by Leech Lake, a tributary of the Mississippi River via the Leech Lake River. Leech Lake and Lake Winnibigoshish lie within the Leech Lake Reservation and are the first two of the six controlled lakes that make up the Mississippi River headwaters lakes system. Of the six headwaters lakes, Leech Lake and Lake Winnibigoshish contain approximately 75 percent of the system's capacity.

**Historical Perspective**. The six water control dams on the lakes in the Mississippi headwaters area were constructed by the U.S. Army Corps of Engineers between 1881 and 1913. The original purpose of the dams was to "improve navigation and provide some minor benefits to logging." Congressional authorization in 1880 for construction of the headwaters reservoir system was promoted by powerful Minneapolis water and milling interests that received the greatest benefits from construction of the dams.

The United States made no effort to consult with the Leech Lake Band, whose land and natural resources they were proposing to destroy in order to assure Minneapolis' future as a great center of commerce and industry. Only after construction had begun on the headwaters dams, did Congress direct the Secretary of the Interior to estimate damages to the property of "friendly Indians." The Commissioner of Indian Affairs could not get enough evidence to make a reasonable estimate of the damages, but a study concluded that damages would be great and estimated that a sum of $26,000 per year would cover the damages.

The Commissioner of Indian Affairs and the Secretary of the Interior accepted the award and recommended a settlement of $10,000 for destruction of property together with an annual appropriation of $26,000 to cover loss of sustenance. No action was taken until April, 1886 when the Commissioner of Indian Affairs requested that $144,038 be paid to the Indians for damages for the years 1883 to

1887. No congressional action was taken. The matter was then handled by both the Northwest Indian Commission and the Rice Commission appointed pursuant to the Nelson Act. The Northwest Indian Commission eventually induced the Indians to accept a sum of $150,000 for damages, which was then included in the recommendation of the Nelson Commission. In neither instance was the question of ongoing annual damages discussed.

The United States Engineer reported that the dams flooded a total of 46,920 acres. This destroyed gardens, rice fields, hay lands, fisheries, and graveyards. The Rice Commission in a 1889 report wrote that the loss is an annual and perpetual loss because it was a loss of the Indians' almost sole subsistence. As noted by Commissioner Rice and his fellow commissioners:

> "The injury done them in building the reservoir dams was without a doubt very great. Two or three of their burying grounds were so washed by the overflow that the remains of their buried dead were unearthed and scattered along the shore. This desecration but added poignancy to the sorrow caused by the loss of subsistence."

Eventually the $150,000 was appropriated by Congress in 1890 was paid out, according to the General Accounting Office, two-thirds to the Pilalger and Lake Winnibigoshish and one-third to the Mississippi Chippewas. In 1897 Congress also passed a law which provided:

> "that all lands acquired and sold by the United States under the Act for the relief and civilization of the Chippewa Indians in the State of Minnesota, approved January 14, 1889, shall be subject to the right of the United States to construct and maintain dams for the purpose of creating reservoirs and aid of navigation, and no claim or right of compensation shall accrue from the overflowing of said lands on account of the construction and maintenance of such dams or reservoirs."

Obviously the various dams were built for aiding navigation. Just as already, the damages done to the Indians of the Leech Lake Reservation as a result of building the dams have never been adequately addressed. If adjusted for inflation and interest, the sum of $26,800 per year assumes a rather staggering proportion when multiplied by the hundred odd years since the dams were authorized. The Minnesota Chippewa Tribe's suit for damages against the U.S. Government was settled in 1984 for approximately $2.2 million.

Throughout the history of the headwaters lakes, tribal rights and interests have been subjugated to the interests of more powerful groups. The Minneapolis manufacturing and water power interests that pushed for construction of the headwaters dams influenced their operation for many of the early years. Dams on Leech Lake and Lake Winnibigoshish have also been operated to prevent flood damages to agricultural lands in the Aitken area and this has caused severe damage to tribal wild rice crops. These damages went unacknowledged by the Corps of Engineers until recently.

In the 1930s the Corps of Engineers constructed a series of locks and dams at and below Minneapolis to provide a 90 foot navigation channel at flows down to 350 cfs. This eliminated the need to use the headwaters reservoir to maintain navigation downstream from Minneapolis. Nevertheless, a number of other upstream and downstream interests have remained concerned about the operation of the headwaters lakes. At the request of some of these interests, Congress requested a study of the headwaters lakes in 1945 to recommend modifications to enhance flood control, recreation, fish and wildlife and other uses. This study was not completed as scheduled, but in 1976 (another low-flow year) the study was reactivated and it was completed in 1982. The Leech Lake Band of Chippewa Indians participated in the study during these years to provide the Corps of Engineers with an understanding of their unique cultural, legal, political and economic status. As a result, operating plans for Leech Lake and Lake Winnibigoshish were refined to enhance wild rice production as well as fish and wildlife habitat. It is interesting to note that prior to tribal participation in the headwater's study, the St. Paul District was unaware of its responsibilities in fulfilling the U.S. Government's trust relationship with American Indian tribes.

This historical account provides some insight into the vehement opposition of the Leech Lake Band of Chippewas to the proposed use of reservation waters in 1988 to supplement Twin Cities water flows. The band has suffered grievous losses of their land and natural resource base to accommodate Minnesota's growth over the past one hundred years. Today over 75% of Indian households on the Leech Lake Reservation live below the national poverty level. Unemployment, alcoholism, illiteracy, and other social blights are pervasive problems among Indian populations today. The position of the Chippewa people may be difficult to understand without this history of disenfranchisement.

**Wild Rice Resources**. Wild rice once grew throughout the Great Lakes region and the northeastern United States. Changes in land and water use over the past 100 years have dramatically reduced its range and abundance. The Leech Lake Indian Reservation contains the highest concentration of naturally occurring wild rice in the world. This is the primary reason the territory was reserved by the Chippewa people for a permanent homeland.

When compared with other years, 1988 was a bumper crop year for wild rice production on the Leech Lake Reservation. In poor years, harvest rates have been below 50 pounds per acre. Bumper crops occur on the average of once every five years; in this context, the 1988 crop alone represents about 44% of production within a five year cycle.

The value of the wild rice crop is low in comparison with market values over the past 20 years. Prices paid to harvesters for the green rice have varied from approximately $4.00 (1988 dollars) per pound in 1972 to $0.65 (1988 dollars) in 1987. Processing of wild rice reduces its weight by 50 to 60%. The market price of processed wild rice was $4.50 per pound in 1987. Individual harvesters have generally adjusted to market conditions by selling more wild rice when market prices are high and retaining it for subsistence use when prices are low. Over the past 20 years band members have marketed about 70% of the crop and retained 30% for their own consumption. While not scientifically verified, wild rice pickers estimate they harvest about one-third of total lake production; the remainder is consumed by wildlife or natural reseeding of the bed.

Wild rice is an aquatic grass and an annual plant, growing from seed each season. As such, plant stress can have profound effects on production. Wild rice grows best in one to three feet of water. The plants grow in depths outside of this range but produce less seed. The major effect of drawdown on wild rice plants in the reproductive stage is on the physical stability of the plants. As more of the supporting stem emerges, the likelihood increases that wind and water action or plant weight will "topple" the plants (this process is called "lodging"). Lodging may not kill the plant or affect seed formation, but it causes severe problems with harvesting.

The proposed drawdown of Lake Winnibigoshish would have reduced the water depth needed to harvest the crop. Wild rice traditionally is harvested by two individuals in a canoe. One individual stands in the front or rear and uses a long slender pole to propel the canoe through the bed; the other sits in the middle and harvests the wild rice using a pair of flails or knockers to knock ripe seeds off the plants. The seeds do not ripen at the same time, and the same bed is harvested many times over during the season, which generally lasts from mid-August to October. The majority of wild rice is harvested from Lake Winnie and its flowages between August 20th and September 15th.

When informed of the proposed drawdown of the headwaters lakes to supplement Mississippi River flows, the Leech Lake Band attempted to calculate the effect on wild rice resources, and a survey of the resources affected by Winnibigoshish Dam operations was conducted. Estimates of probable economic losses were developed based upon Corps of Engineers' projections of pool elevations under no rain conditions. Predicted results showed a potential loss of 20-40% of the 2,700 acres of wild rice within the flowage <u>without</u> additional or supplemental water withdrawals. Release of an additional 300 cfs from Winnie Dam increased losses to a range of 33-62%. These losses are based only upon the ability to harvest. Additional losses from increased wind damage (plant lodging) also could be expected. We estimated a potential economic loss approaching $250,000 if the water drawdown occurred.

This economic loss must be placed in social perspective. Harvesting, processing, consumption, and sale of wild rice is done by families living on about $10,000 per year. Ricing may provide 20% of a family's annual income, and it substantially reduces their food costs.

Gathering and preparing wild rice is an activity that has deep cultural and religious significance to Chippewa people. The traditional gathering of families for the wild rice harvest is as important to Chippewa people as Christmas is to Christians.

**Fisheries and Wildlife**. Fish and wildlife resources within the Leech Lake Reservation also are affected by the operation of the Mississippi headwaters lakes. As with wild rice, Leech Lake Band members depend upon these resources for income and subsistence. Leech Lake and Lake Winnibigoshish support a world famous sport fishery, which is the basis of the reservation's resort and tourism industry. Commercial harvesting of whitefish, lake herring, and baitfish are important industries that allow band members to derive income in an economically depressed area. Trapping of furbearers is economically important to many reservation families, and production of furbearing mammals is sensitive to changes in water levels. The Leech Lake Reservation produces a large percentage of the state's waterfowl and this production also is sensitive to headwaters lakes operations. During drought conditions, reductions in fish and furbearer habitats and subsequent resource production losses are likely.

**The 1988 Drought**. Until their 1978 study, the U.S. Army Corps of Engineers apparently was largely unaware of the unique legal and political status of American Indian tribes and the specific trust relationship between the executive branch of the U.S. Government and Indian nations. The Leech Lake Reservation's participation in the headwaters study brought tribal interests into an already difficult process of balancing diverse and conflicting needs and desires. Much to the Corps' credit, they accepted the challenge and incorporated management features into operating the headwaters lakes to enhance fish, wildlife, and wild rice resources on the reservation. Moreover, the Corps recognized the sovereign status of the Leech Lake Band and incorporated policies and protocol into the Corps' decisions on a government to government basis, as was intended by tribal leaders and the U.S. Congress when they ratified treaties over a century ago.

As drought conditions worsened over the summer of 1988, Governor Perpich organized a drought task force to assess drought problems and propose mitigative measures. When task force and media attention was focused on metropolitan area water use, specifically low flows in the Mississippi River, northern constituencies immediately responded to defend their interests. A variety of northern organizations contacted the Reservation's government to enlist support for opposing the "inevitable" move to supplement the Mississippi River flows by drawing down the headwaters lakes.

Tribal representatives were invited to attend the Governor's Drought Task Force meeting at which the criteria for requesting a withdrawal of water from headwaters lakes were determined. The Leech Lake Band of Chippewas reserved judgement on the task force decisions to evaluate the problems associated with low river flows. After further evaluation the tribe objected to the release of supplemental flows based on the following rationale:

1. There was no emergency with respect to Twin Cities municipal water supplies. After restrictions on irrigation withdrawals and other conservation measures, there would be sufficient flow in the river to meet municipal water use demands during drought conditions.
2. Power production is affected by low flows, but not to a degree which constitutes an emergency.
3. Supplementing low flow conditions in the Twin Cities area would maintain water quality and aquatic resources. The proposed release of headwaters lakes water looked more like a trade-off of in-stream uses than a water supply or power production crisis. The issue then became whose in-stream uses have a higher priority? Also, many issues other than low flow conditions contribute to metro area water quality problems. For instance, land use practices in the Minnesota River Valley have impaired waste assimilation capabilities within the metro area. Why should the Leech Lake Band sacrifice resources and income to mitigate the adverse effects of other's land use practices?
4. Supplementing low flows sets a precedent creating a reliance on headwaters resources by Twin Cities water users. Water is the first limiting factor to

human settlement and industry. A perception that water can be obtained from the headwaters to support future growth in the Twin Cities area effectively limits the reservation's future potential for growth and development. It may also lessen the perceived need for careful and prudent planning in the use of metro area land and water resources.

**Conclusions and Recommendations.** Not all present uses of the Mississippi River can be met during periods of low flow. The Leech Lake Band of Chippewa Indians will continue to protect and defend tribal waters and related resources for harvest of wild rice and fish and wildlife. Managing these resources contributes to the health and growth of the reservation's tourism industry.

Maintenance of water quality and aquatic life in the Mississippi River at the Twin Cities is best accomplished by eliminating sources of pollution rather than relying on water from other areas. Avoiding future urban water use restrictions during drought conditions may require improvement of the water supply infrastructure, which should also include an alternative or reserve water supply to the Minneapolis water supply system.

Finally, and most importantly, all citizens should receive accurate information on the nature and extent of water related problems and restrictions. The drought of 1988 produced a number of misconceptions about the problems and their severity. The only "real" solution, after all, was rain.

## Panel V: REGULATORY ASPECTS: AUTHORITIES AND ISSUES

**CHAIR: JACK DITMORE**
Deputy Commissioner, State Planning Agency

**Federal Regulatory Issues:**

What is the authority of the Corps of Engineers (CoE) to regulate releases from the headwaters reservoirs? What plans have been developed to guide the CoE in carrying out their authorities? As a result of the drought of 1988, is the regulatory role of the CoE likely to change?

**Regulating Water Quantity:**

What are the priorities of the State of Minnesota regarding water use during periods of drought? How is the state priority system applied and who administers it? How are permitting decisions made? Can withdrawals be limited, and how? Do state regulations for water allocation account for instream flow demands for fish and wildlife and water quality protection? Should the system of priorities for regulating water withdrawal and use be revised?

**Protecting Water Quality:**

What is the regulatory framework for protecting water quality in Minnesota, particularly in respect to the Mississippi River as it flows through the metropolitan region? To what extent do federal regulations affect the state's regulatory role? How do water quality regulations affect the quantity of water which can be withdrawn from the Mississippi River? Can the regulation of discharges be revised to help meet the demands for other uses of the river and still meet water quality protection goals?

Legal issues regarding the allocation and regulation of water use assume unusual importance during times of drought. This panel reviewed these issues and discussed the adequacy of present legal authorities of federal and state agencies to manage water resources in the Mississippi River during such periods of water scarcity.

### Regulatory Issues: Authority and Issues

Stan Kumpula, Assistant Chief, Engineering Division, U.S. Army Corps of Engineers, St. Paul District

Corps of Engineers Authorities for Regulation of the Headwaters Reservoir:

The Rivers and Harbors Acts 1880 and 1882 provided the authority to construct the headwaters reservoir dams to provide supplemental flows for navigation. Prior to the Act, there were wooden dams operated by private interests to supplement water flow for logging. In the 1880 Act, Congress gave the Secretary of the Army authority to develop regulations on the use of headwater reservoirs "... as in his judgement the public interest and necessity may require ..." Regulations written in 1889 were general and not specific to reservoir elevations or flows.

The current regulations were published in February 1936 and amended in January 1945. The regulations were authorized by Congress, which gives them the force and effect of law.

Other reports and surveys dating back to the 1870s have been prepared. Only reports specifically authorized by Congress could be implemented. Projects authorized and implemented include: (1) straightening of the Mississippi River channel between Winnibigoshish and Pokegama lakes and from Leech Lake Dam to the mouth of the Leech Lake River, completed in 1926; and (2) flood control improvement in the vicinity of Aitkin by means of a flood diversion channel, completed in 1956. The 1982 feasibility study is the most recent report on the headwaters reservoirs. It recommended only minor changes in the reservoir regulation plans that could be implemented under existing authorities. These were: (1) to continue the trial regulation plan to control normal summer erosion on Lake Winnibigoshish and (2) to stabilize Leech Lake on the low side of the summer regulation range (1294.5 to 1294.9 ft), whenever possible for wild rice production.

**Regulation Plan.** In the published regulations the St. Paul District Corps of Engineers regulates the headwaters reservoirs between the elevations in Table 2, whenever possible. The normal summer regulation range is listed in the table for comparison. The current regulation plan attempts to regulate the reservoirs in a manner more consistent with current purposes. In this respect, published minimum outflow requirements, which are stated in terms of minimum average annual flows are not entirely consistent with current minimum flow requirements shown in Table 8. Informal requirements have been agreed to between the Corps and the DNR, but situations can exist where informal minimum release requirements would be contrary to existing law. For example, the informal minimum flow requirements (Table 8) fit within the published requirements unless spring runoff is very low and the published minimum average annual flow is not met. To date, this has not happened.

In accordance with the Corps' informal release plan, if headwater reservoir elevations decline to the minimum elevations shown in Table 2, release rates are reduced to 50% of the values shown in Table 9. The St. Paul District of the Corps has the authority to modify this plan for low flow conditions and to use

Table 9. Headwater Reservoir

| Reservoir | Minimum Release (cubic feet/second) |
|---|---|
| Winnibigoshish | 100 |
| Leech Lake | 100 |
| Pokegama | 0 |
| Sandy | 20 |
| Pine | 30 |
| Gull | 20 |
| Total | 270 |

the available reservoir storage volumes down to the minimum stages shown in Table 2. This is in a manner that serves the overall public interest and follows the Native American Trust.

**Future Roles of the Corps of Engineers.** Studies are underway to examine reservoir regulation during low flow periods to determine if any adjustments need to be made or if the published regulation needs to be revised. The studies include extensive coordination with the Minnesota Department of Natural Resources and Pollution Control Agency, and they will provide an assessment of water needs for recreation, wild rice production, and other headwater reservoir uses. In addition, they will define more precisely the downstream flow needs for water supply, water quality, instream flow, and other uses identified during the study. The St. Paul District will develop an interim drought contingency plan for the summer of 1989 and a more final plan by 1990 or 1991.
The Water Resources Development Act of 1988 states the following:

> SECTION 21: <u>MISSISSIPPI RIVER HEADWATERS RESERVOIRS</u>
>
> (a) GENERAL RULE.--Notwithstanding any other provision of law, the Secretary (of the Army) is directed to maintain water levels in the Mississippi River headwaters reservoirs within the following operating limits: Winnibigoshish 1296.94 feet--1303.14 feet; Leech 1293.20 feet--1297.94 feet; Pokegama 1270.42 feet--1276.42 feet; Sandy 1214.31 feet--1218.31 feet; Pine 1227.32 feet--1234.82 feet; and Gull 1192.75 feet--1194.75 feet. Such water levels shall be measured using National Geodetic Vertical Datum.
>
> (b) EXCEPTION.--The Secretary may operate the headwaters reservoirs below the minimum or above the maximum water levels established in subsection (a) in accordance with a contingency plan which the Secretary develops after consulting with the Governor of Minnesota and affected landowners and commercial and recreational users. The Secretary shall transmit such plan to Congress within six months after the date of the enactment of this Act. The Secretary shall report to Congress at least 14 days prior to operating any such headwaters reservoir below the minimum or above the maximum water level limits specified in subsection (a).

The St. Paul District will use results of current studies to respond to the above requirement.

## Water Supply Issues in the Metropolitan Twin Cities Area

James Japs, Water Appropriation Program Coordinator, Minnesota Department of Natural Resources, Division of Waters, St. Paul, MN

This paper will present a brief history of Minnesota water law and then discuss the response to the 1988 drought.

Minnesota's water appropriation law was first enacted in 1937 (Minnesota Statutes Chapter 105) near the end of the drought of the 1930s. The act established a water policy for the state and a permit system to regulate water users. The most important changes to the original law, which were adopted in August of 1980, include requirements for submitting annual water use reports, repeal of the exemption for so called "grandfather appropriators," the establishment of a priority system for water use, and the requirement to establish rules governing the allocation of waters which were adopted in August of 1980, Part 6115.0620 of Minnesota Rules requires that a permit be obtained for appropriation of water in excess of 10,000 gallons per day or one million gallons per year. In order to obtain a permit to appropriate water the applicant must own or control (lease or rent) land abutting the surface water source or overlying the groundwater source. Applications are evaluated to determine the effects of the proposal on the environment and other higher priority water users.

In 1973, the legislature established five priority classes of water use. The first priority is domestic water supply, excluding industrial and commercial uses of municipal water supplies. Second priority is users of water involving consumption of less than 10,000 gallons per day. Third priority is agricultural irrigation and processing of agricultural products. Fourth priority is power production and fifth priority is all other uses involving consumption in excess of 10,000 gallons per day.

These priorities become important in resolving water use conflicts when competing demands exceed the reasonably available supply of water. If the conflict cannot be resolved by other alternatives these priorities are used. Highest priority water users shall be satisfied first and any remaining available water supply is allocated to the next users.

While environmental protection is not listed in the priority system, Minnesota statutes and rules establish resource limitations below which no appropriation can occur. These establish protected flows for watercourses, protection elevations for water basins and safe yields for groundwater sources. Currently, these are 43 established protected flows, about 12 protection evaluations, but no established safe water yields.

**1988 Drought**. During the summer of 1988, permits were suspended in 13 watersheds where river levels were at critically low levels or were below established protected flows. A total of 195 surface water permits were suspended, including 167 for agricultural irrigation, 17 golf courses, and 11 other types of appropriations. While the drought affected all rivers in Minnesota, smaller rivers were first to show major impacts. Appropriations within some smaller watersheds were suspended to protect instream flow requirements and the rights of higher priority water users within the watersheds. Six of the suspended watersheds are tributaries of the Upper Mississippi River above the Twin Cities metropolitan area. The suspensions were perceived by some to preserve water for lawn watering and other nonessential uses in the Twin Cities.

St. Paul derives most of its water supply from the Mississippi but also uses a reservoir system and four wells installed after the 1976-77 drought. Minneapolis relies entirely on the Mississippi River for its municipal supply. There was reluctance from both cities to implement conservation measures. It was difficult to tell farmers to stop pumping water for irrigation, knowing their crops would die, when people downriver continued to water lawns and little was being done to promote water conservation.

The impact of the drought on the Mississippi River aroused concern early in the summer. A Drought Task Force was established chaired by Ron Nargang, Director of the Minnesota DNR, Division of Waters. The task force included representatives from many federal and state agencies, power producers and the cities of Minneapolis and St. Paul. Agreements were reached with Northern States Power Company, St. Paul, and Minneapolis to reduce water use if flows at the Coon Rapids Dam fell below 1,000 cfs for 24 hours. This occurred on July 25, and the conservation measures were implemented. About the same time Governor Rudy Perpich requested the Army Corps of Engineers to release water from one or more of the six headwaters reservoirs. Many people from northern Minnesota were opposed to a release in part because it was viewed as robbing Peter to pay Paul. The opposition was compounded by the perception that Minneapolis and St. Paul had done too little too late to reduce water use.

Whether these perceptions are right or wrong, they show the need to determine trigger points at which conservation measures should be implemented. Drought is a natural occurrence and should be anticipated as such. The only solution is to reduce water requirements and develop contingency plans and alternative water sources. Some municipalities and industries have investigated or implemented changes since the last major drought in 1976-77. The Department of Natural Resources prefers to see voluntary conservation measures taken by all water users rather than mandatory suspensions or restrictions.

The request for a headwaters release was rejected. Shortly after the rejection, 10-12 inches of rain fell in the headwaters area, and flow of the Mississippi River increased sufficiently to remove water use restrictions in the Twin Cities on August 17, 1988. The request for a headwaters release was rejected based on Native American water rights and the economic impacts on other riparian land owners. Even though these issues were not entirely resolved, the Drought Task Force was successful in coordinating drought-related water issues with all involved parties.

**Groundwater.** Groundwater was a less visible issue during the drought. The drought caused some municipal wells to break suction or even go dry. Construction of new wells or water use restrictions were taken to resolve these problems.

There were many inquiries from domestic well owners alleging well interference due to irrigation, but only 21 formal complaints were received. Domestic wells must be inspected by a licensed well driller to determine if the problem is caused by poor well construction or other causes before the DNR investigates. If the complaint is valid, the irrigator is responsible for providing the domestic well owner with an adequate water supply. There were several valid well interferences in 1988. Without adequate recharge, there may be more next year.

**Drought Legislation.** Minnesota's water appropriation laws are good, but the effectiveness of these laws should be evaluated. The adequacy of current water use priorities also need to be evaluated. One example of confusion that is often cited is that irrigators cannot use their electric pumps if power producers are shut down before irrigators. The solution to this problem is not as easy as changing power production from fourth priority to second priority. The differences in water use also need to be considered. Agricultural irrigation accounts for 5% of the total water use in Minnesota and only 1% of the total surface water use. On the other hand, power production accounts for about 50% of the total water use in the state but less than 1% of the total groundwater use in Minnesota. There is little chance of conflict between these two types of water users because they utilize different sources of water.

Most of Minnesota's water use involves the last two water use priorities. There is a need to look at the environmental and economic impacts relating to these water uses. Changes in water use priorities, however, should be based on actual rather than perceived conflicts with the existing system.

Minnesota Rules (6115.0600-6115.0810) regarding water appropriation of water relate mostly to agricultural irrigation, and about 4,000 of the 6,000 active permits authorize appropriation for agricultural irrigation. Two-thirds of the active permits thus authorize only 5% of the total water use. These rules should be expanded to further address larger water users.

Water appropriation rules also need to be updated to reflect new trends in water use like pumpouts for contamination confinement and removal. Most of these pumpouts discharge water to sanitary or storm sewers. Alternative uses for this water, such as non-contact cooling or treatment and reuse of the water for municipal purposes should be considered.

**Regulatory Issues Regarding River Water Quality in the Metropolitan Area**

Russell C. Felt, Section Chief, Water Quality Regulatory Compliance Section, Minnesota Pollution Control Agency, St. Paul, MN

The Minnesota Pollution Control Agency regulates point source discharges to waters of the state pursuant to authority in state statutes and rules and under an Environmental Protection Agency delegation of authority from the federal Clean Water Act. A National Pollutant Discharge Elimination System (NPDES) permit is issued by the MPCA for such discharges. The Metropolitan Wastewater Treatment Plant, located just downriver from St. Paul near Pigs Eye Lake, is the most important point source discharge to the Mississippi River in the metro area. The metro plant discharges about 220 mgd of treated wastewater to the river. Because of the magnitude of the discharge relative to the river flow during critical low flow periods, the NPDES permit contains discharge limits based on water quality needs rather than on the limits of secondary treatment technology applied to most sewage treatment plants.

The MPCA has a statewide critical low flow limit to protect water quality standards. The low flow standard (7Q10) is the seven-consecutive-day low flow average, that occurs with a frequency of once in ten years. The summer 7Q10 used for the metro plant's discharge is approximately 1,600 cfs measured at the Robert Street Bridge in St. Paul. The water quality standards of concern are dissolved oxygen (DO) to be maintained at or above 5 mg/L and ammonia in the un-ionized form to be maintained at less than 0.4 mg/L. Effluent limits for the metro plant that correspond to the water quality standards are 10 mg/L $CBOD_5$ (five-day carbonaceous biochemical oxygen demand) and 5 mg/L total ammonium.

Flow rates in the Mississippi River measured near downtown St. Paul got as low as 800 cfs during the summer of 1988, or about half the 7Q10. The metro plant performed well with an average $CBOD_5$ of 6 mg/L, ammonium of less than 1 mg/L and an effluent DO of 7 mg/L or more. Dissolved oxygen levels in the river held up very well considering the low flow and upstream problems caused by the Minnesota River, in which DO levels at times were in the range of 3-4 mg/L. This caused DO in the Mississippi River just upstream of the metro plant to fluctuate around the 5 mg/L standard. The metro plant discharge caused about a 0.5 mg/L decrease in river DO downstream. On average during the low flow period the 5 mg/L DO standard was met downstream of the plant, but on some days when the upstream DO was near or below 5 mg/L, the DO downstream went as low as 4 mg/L. (See Figure 20).

The upstream DO problem on the Minnesota River this past summer is attributable to flow characteristics of the lower Minnesota River, two sewage treatment plants, and nonpoint sources of pollution. Programs are in place to upgrade the sewage treatment plants and to address the nonpoint source pollution. With these improvements, the impact of future low flows comparable to those of 1988 should be less severe than we experienced. However, if river flows go significantly lower, we may experience lower DO levels than this past summer in the ten mile stretch of river below the metro plant.

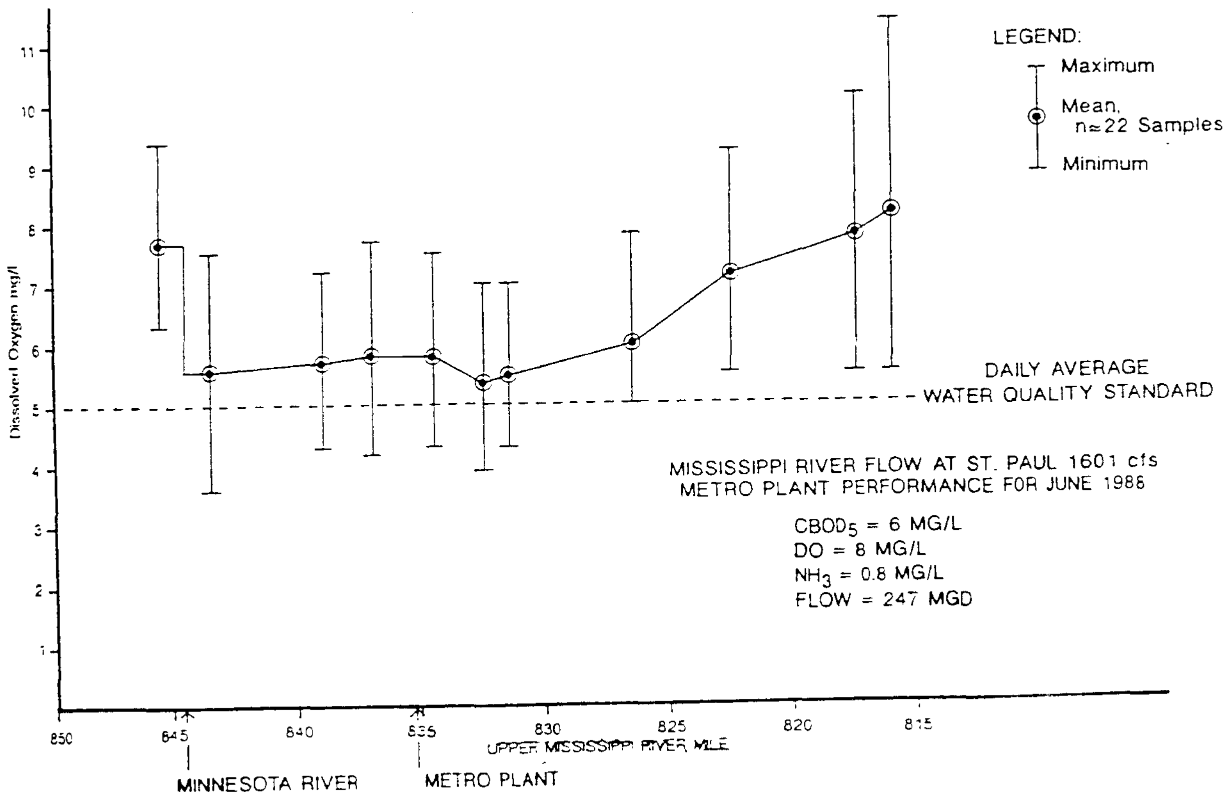


Figure 20

**Panel VI: ALTERNATIVE WATER SUPPLY POSSIBILITIES**
**(including water conservation and re-use)**

**CHAIR: H. G. STEFAN**
St. Anthony Falls Hydraulic Laboratory
Department of Civil and Mineral Engineering
University of Minnesota

A large number of issues must be resolved before plans can be finalized to provide alternative water supplies for Minneapolis and other parts of the Twin Cities metropolitan area. Indeed, as discussions of preceding panels demonstrate a consensus is yet to be reached on the nature and magnitude of the problem that needs to be resolved. Whether the solution to water supply and water use problems in the region will involved structural solutions (development of new supply sources), better distribution of existing sources, lessening of demands by improved water conservation practices, or a combination of these approaches cannot be stated at the current level of problem definition. This panel summarized the various issues that need to be resolved relative to water supply planning for the region's needs during future droughts and reviewed studies conducted in the past on the feasibility of physically-based solutions (development of new supplies). Panel members concurred that water conservation is an important long-term strategy in water resources management but recognized its limitations in resolving the complex web of conflicting uses for Upper Mississippi River water in times of drought. Finally, the issue of groundwater contamination within the metropolitan area was discussed in the context of difficulties that may arise if further demands are made on that resource.

## SOME ISSUES

1. Water Needs
   * How much water is needed for different purposes under drought limited supply conditions?
   * How much water is needed for different purposes under emergency/spill conditions?
   * Can a supply system be found that will satisfy both needs simultaneously?
   * Regional water uses that must be provided for include: municipal water supply, electrical power production, industrial uses, irrigation and other agricultural uses, maintaining waste assimilative capacity, maintaining river/stream/lake ecosystems, and navigation

2. Time Constraints on Supplies
   * How quickly will different users run out of water at present?
   * For how long must a minimum water supply be guaranteed?
   * How quickly can an alternative water supply be provided?

3. Sources
   * Where can the water be found, how much of what quality, at what cost, and with what legal/regulatory constraints?
     Consider:
     a. Surface water:
        - Should the headwaters reservoirs be used?

- Should new on-stream reservoirs or new off-stream reservoirs be considered?
- Is interbasin transfer, specifically from St. Croix or Lake Superior feasible?
- Can existing minepits in the Crosby area be used?

b. Groundwater:
- Is there enough groundwater? How will groundwater withdrawal affect surface water flows downstream?
- Will massive use of aquifers in the metro area reduce availability of groundwater to isolated users outside or within the metro area?
- Will expansion of well systems in the metro area for normal use affect aquifers and supplies at time of drought?
- Are the aquifers in the glacial drift to the north of the metro area of use?
- Should the metro area have a groundwater allocation plan?

4. Conservation
   * How much water can be conserved and where?
     Consider:
     a. Domestic uses
     b. Air conditioning/commercial/industrial
     c. Sprinkling
     d. Leakage in distribution systems
     e. Lake conservation
     f. Energy conservation
   * Where and how is re-use of water possible?

5. Socioeconomic Concerns
   * How can socioeconomic conflicts be resolved before a drought by negotiation?

6. Timing of Actions
   * What can be done in the short-term, i.e. for next year?
   * What actions can be taken in the intermediate term, i.e. next 10 years?
   * What plans can be made for the long-term?

Some Alternatives. Session members ranked alternatives from 1 (highest) to 14 (lowest).

| <u>Rank</u> | <u>Range</u> | |
|---|---|---|
| 1. | 1 to 6 | Be prepared for water conservation measures in case of drought. Use a marketing approach to educate the public on water conservation. Have an education plan. |
| 2. | 1 to 12 | Allocate groundwater withdrawal in the metro arc based on groundwater model. |
| 3. | 1 to 8 | Require each city to have two independent water sources to guard against pollution emergencies. Second source may be only fraction of first. |

| | | |
|---|---|---|
| 4. | 1 to 13 | Save enough groundwater capacity in entire metro system to provide 100 percent supply during consecutive periods of drought and allow for loss of groundwater capacity due to pollution. |
| 5. | 2 to 10 | Consider well fields near river corridors. |
| 6. | 4 to 10 | Reexamine and change headwater reservoir operating rules; negotiate with other constituencies. |
| 7. | 5 to 11 | Facilitate inter-city water sales and network connections. |
| 8. | 2 to 12 | Consider a Metropolitan Water Authority to plan inter-city distribution of water, coordinated resource allocation, etc. (Could be part of Metropolitan Council.) |
| 9. | 3 to 13 | Consider withdrawal of surface water from (mouth of) St. Croix. |
| 10. | 2 to 13 | Examine and negotiate storage in existing Mississippi River impoundments upstream from metro area (not headwater reservoirs). |
| 11. | 4 to 11 | Reduce metro energy consumption at time of drought because it conserves water. |
| 12. | 2 to 13 | Plan so that drought and emergency spill situations are resolved simultaneously. |
| 13. | 6 to 12 | Consider new surface water reservoirs. |
| 14. | 14 | Do not consider re-use (too costly) or interstate transfer (too political). |

## Alternative Water Supplies for the Twin Cities Metropolitan Area

Douglas W. Barr, Barr Engineering Co., Minneapolis, MN

Studies performed in the 1970s predicted the need for increased water supplies for the Twin Cities metropolitan area ranging from 270 cfs to 1,700 cfs by the year 2020 (Table 9). Some of the possible sources of that auxiliary supply are:

Table 10. Summary of Various Alternatives for Providing Augmentation in the Year 2020 - Annual Cost in Millions of Dollars*

| Assumed Population & Consumption | Mississippi Pumpback: From Below Grey Cloud | Mississippi Pumpback: From Pt. Douglas | St. Croix Pumping: Route A | St. Croix Pumping: Route B | Upstream Reservoirs | Ground-water** | Upgrade Sewage Treatment Plant |
|---|---|---|---|---|---|---|---|
| High | 2.79 | 4.00 | 3.02 | 2.98 | 7.10 | 9.67 | 9.00 |
| Medium | 1.48 | 2.12 | 1.68 | 1.63 | 2.10 | 5.32 | 4.50 |
| Low | .45 | .65 | .52 | .55 | .18 | 1.32 | 1.30 |

* Costs are based on the assumption that the listed alternative will be used exclusively in developing the necessary augmentation. Costs are in 1973 dollars.

** Costs include water supply and recharge facilities, plus $2.07 million/year for replenishing the base flow of the river for high and medium assumptions and $0.65 million/year for the low assumption.

**Groundwater**. Some of the supply could come from increased pumping from aquifers. Long-term limits on the rate of pumping from groundwater are about 600 cfs. Beyond this rate, injection of water into the aquifers would be necessary to increase the amount taken. Increased pumping would have increasingly serious effects on the lakes, marshes, and streams in the metropolitan area.

**Upstream Reservoirs**. There are potential reservoir sites in the Mississippi River, Rum River, and the Crow Wing River. These sites would be similar to the reservoirs in the headwaters of the Mississippi River, which are now unavailable because of recreational demands and distance from the Twin Cities. The new reservoir sites would be closer to the metropolitan area and could more quickly replenish water for our needs.

**Pumpback Along the Mississippi River**. Water could be pumped from the Mississippi River below the Hastings Lock and Dam, or even from the pool behind the dam, and piped to the Mississippi River upstream of the sewage outfall at the Pig's Eye Plant. This would permit greater consumptive use of the Mississippi River flow upstream of the metropolitan area. Water also could be pumped over the dams to reach the intakes of the Minneapolis and St. Paul water treatment systems. This alternative presumes sufficient dilution and assimilation of the sewage at the point of the pumpback.

**Pump From St. Croix River**. It may be possible to pump water from the St. Croix River near Stillwater and transport it across the northern limits of the metropolitan area to discharge into the Mississippi River upstream of the water supply intakes. As a result, water levels at Stillwater would vary by a maximum of four inches, which is small compared to natural water level fluctuations. The pumped water could be carried all the way by pipeline but there are also several routes where the water could be conveyed by a combination of pipeline, open channels, natural streams, and bodies of water (see Figure 21).

**Upgrade Sewage Treatment Plant**. Water to assimilate discharge from metropolitan sewage treatment plants creates a major demand for water. A higher standard of treatment in the plant could permit greater appropriation of the Mississippi River water for consumptive uses. For the higher projected demands, it would be necessary to combine some augmentation of water supply with the increased standard of sewage treatment. This alternative would cost more and consume more energy.

**The Diversion From Lake Superior**. Water could be pumped from Lake Superior into the Mississippi River. This alternative has many disadvantages; greater construction cost for a long pipeline, greater pumping costs, the long distance from Lake Superior to the metropolitan area, and setting a precedent of diverting water from Lake Superior.

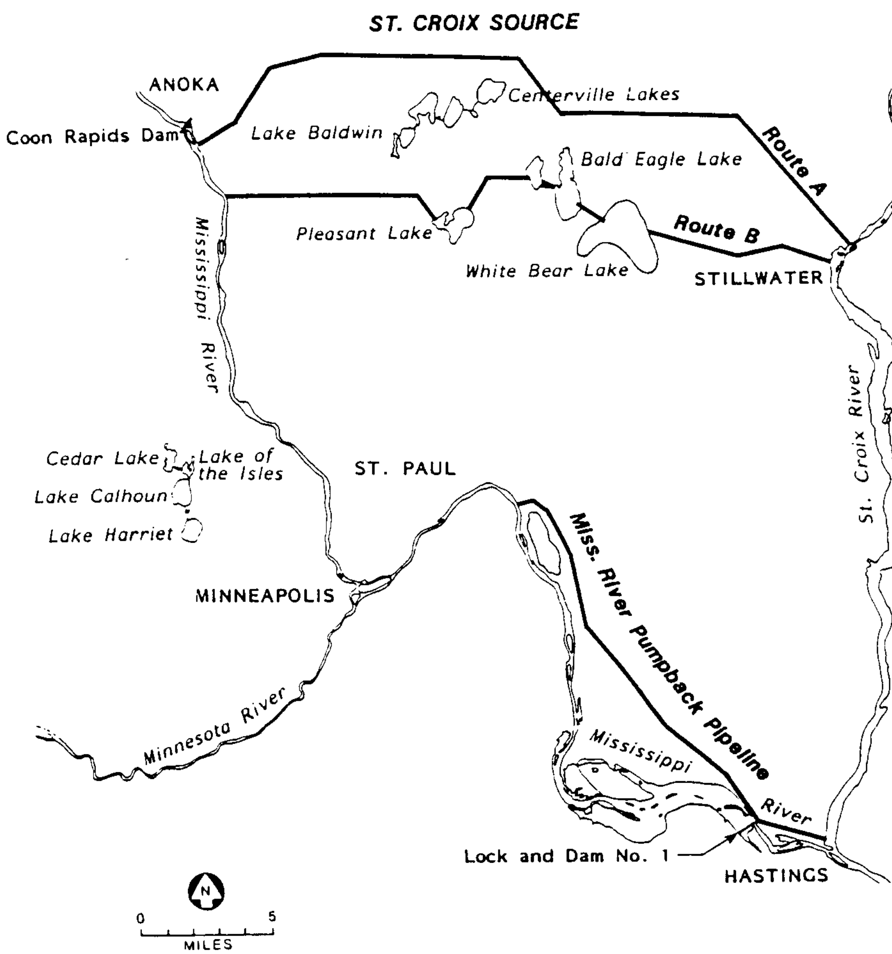


Figure 21. Alternative Water Supplies 3 and 4 (Presentation of Douglas W. Barr, Barr Engineering Co.)

## Water Conservation Issues

Sarah P. Tufford, Minnesota Department of Natural Resources, St. Paul, MN

The discussions of water supply alternatives by others on this panel address meeting demand, not need. Human beings can get along on two gallons of water per day, if necessary, although a reduction in usage to that level represents a major change in lifestyle. Nevertheless, for short periods of time on camping trips, or during power failures, we can and do get along with very little water.

Therefore, it follows that demand can be modified and the amount of demand need not be accepted as a fixed in our discussions. There are many articles documenting the experiences of communities and water utilities in California and in the southeastern U.S. during recent water supply shortages. Demand reductions of 20-50% were achieved, with carry over reductions in demand after supplies were restored to normal levels. The water wasting habits from before the drought are replaced by water conserving behavior that becomes a new habit after the drought.

A water conservation initiative in Minnesota could include:

1. Fully utilizing a present pumping and delivery system by a) repairing leaks and replacing worn equipment, or b) reducing peak demand to more evenly distribute the withdrawal and reduce the need for new pumps/wells that are used only a fraction of the year;
2. Reducing overall per capita demand for water. A necessary result will be an increase in cost per unit volume.
3. Mandating more efficient installations in new housing, air-conditioning systems, and industrial plants, with possible replacement or upgrade requirements for older installations.

Methods to achieve water use reductions involve a) increased price including metering of all service connections; and b) demand management through behavior modification.

Community based promotion of water conservation should include education about the supply and delivery system, description of the amounts of water used in various home activities and suggestions for reducing those volumes. Stickers, leaflets, and coloring books can be distributed to get all age groups involved. Specific issues such as effective landscape watering must be addressed. Watering to wet the entire root zone or allowing grasses to go dormant are choices that can be made. Shrubs and trees need water during dry periods whereas grasses will often survive. Most people do not know how to water, and the watering they do consequently does more harm than good.

Pricing of water delivery to businesses, especially increasing the unit cost for larger volume use, is an effective way to reduce demand. Because water is used mostly as a carrier of wastes, it frequently can be recirculated and consumption can be reduced. Similar reductions can be obtained by recirculation of cooling water in air conditioning systems. Cooling towers or mechanical refrigeration equipment may be needed for greatest efficiency. Setting air conditioners 10-15 °F lower than outdoor temperatures allows for reasonable comfort with lower energy and water demands.

Promoting alternative landscaping with native plant materials suited to the soil type and exposure is also important. Public attitudes toward water use might be examined through a survey and then tested again after a public education effort. The promotion of efficient and wise use might be more effective than an effort to reduce long-term demand during short-term drought periods.
While much of the initiative for water conservation is at the community level, we should have resources at the state level to assist in these efforts. Brochures, presentations, school curricula, and other support materials could be provided. Evaluation of water saving devices and recommendations on their effectiveness and desirability for use in Minnesota could be carried out. A compilation of literature and experiences with water conservation should be maintained.

**Surface Water Storage Sites (Not Considering Headwaters Reservoirs)**

Helmer (Bud) Johnson, Corps of Engineers, St. Paul, MN

**New Sites.** Development of a new reservoir to augment flow in the Mississippi River through the metro area during periods of drought would not be an easy task. There are probably no sites which can be easily or readily developed. Storage at a new site should be sufficient to store water for release over an extended period of low river flows. Storages of 50,000 to 100,000 acre-feet have been mentioned. The site should be located close to point of need to limit transmission losses, and topography at the site should be adequate to minimize surface area exposed to evaporation. The drainage area above the site should be large enough to provide good recharge.

Some sites that meet all or most of the above criteria exist within the Upper Mississippi River Basin (including its tributaries like the Ram and Crow Win Rivers). However, land would need to be acquired, and acquisition costs would be high. Based on studies by the Soil Conservation Service on reservoir sites in the Minnesota River Basin, costs for new sites could range from $300 to $800 per acre-foot of storage. Pumped storage sites rather than reservoir sites could be a cheaper alternative.

**Existing Sites.** Two types of existing sites could be considered: lakes and hydropower pools in the state's major rivers; (a) real estate easements required for increased levels; (b) change in usage; (c) fluctuating levels. People who live on lakes get used to fairly constant levels. Hydropower Pools: (a) same concerns as above; (b) could the existing hydropower pools on the Mississippi above Anoka be increased to provide a low flow augmentation storage?

**Concerns.** Real Estate: (a) condemnation of private lane; (b) tax base reduction to local area; (c) cost of real estate. Environmental: (a) EIS required, water quality, fish and wildlife, rare plants, other. Political: (a) strong pro or con organizations may influence decision.

**Other.** Interbasin Flows: (a) diversion from St. Croix - may be good alternative, however, interbasin transfers are never easy. Wisconsin DNR may have concerns; (b) diversion from Great Lakes - probably very expensive alternative. Has same interbasin transfer problems as above. Strip Mines: (a) may be water quality problem. Treatment required? (b) small watershed (basically groundwater source); (c) travel time could be problem - 3 to 4 weeks from Iron Range; (d) pumping costs will be high; (e) there are also many advantages such as no dam required, small real estate need, minimum environmental impacts, etc.

**Flow Augmentation From Headwaters Lakes During Drought**

Daniel B. Wilcox, Environmental Resources Branch, St. Paul District, U.S. Army Corps of Engineers.

**Past Practices and Effects on Headwaters Lakes.**

Release of water from the Mississippi River headwaters lakes has been used routinely in the past to augment Mississippi River flow during droughts and low flow periods. The routine rate of release during low flow periods on the river is 270 cfs (total) from the six lakes. This rate is used even when inflow to the headwaters lakes is negligible.

There is some potential to increase flow rates to the Mississippi River from the headwaters lakes during a drought, but the need for increased flow must be clearly defined and balanced against effects on the headwaters lakes. Releases from the headwaters lakes must be managed to preserve water in storage in case of extended drought. Releases from the headwaters lakes during a drought must not jeopardize recovery of normal lake levels by the following spring.

Additional drawdown of the headwaters lakes during a drought could compound problems from existing low lake levels. Low summer lake levels can increase wind damage to wild rice. Low lake levels during an extended hot period limit the suitable habitat for whitefish and increase the potential for fish kill due to thermal stress. Low lake levels during winter can affect furbearers by stranding dens and freezing aquatic plants.

Use of boat docks, landings, and connecting channels becomes increasingly restricted as lake levels decline. The perception of unacceptably low lake levels can reduce visitation and thus recreation industry income. Low lake levels limit access to wild rice beds for harvest and reduce an important economic and spiritual activity for the Chippewa Native American people.

**Effects on the Mississippi River.** Aquatic habitat in the Mississippi River upstream of Minneapolis is restricted during drought conditions. Supplemental flow from the headwaters lakes during a drought would have a positive effect on riverine habitat and aquatic life primarily by increasing riffle area.

Water quality in the river upstream of Minneapolis is good and would not be much affected by small increases in flow. In contrast, water quality in Pool 2 (just upstream of Hastings, MN) is marginal during summer low flow conditions, and supplemental river discharge could improve water quality in the riverine portion of the pool.

**Information Needs for Managing Headwaters Lakes.** To determine the feasibility of Mississippi River flow augmentation during a drought, we need to study the effects of water drawdown on the headwaters lakes, routing losses, rates of appropriation, and instream flow requirements for aquatic life and water quality.

Water appropriations within each river reach during a drought will be quantified to determine the streamflow remaining to support water quality and aquatic life in the river. Other studies will determine the amount of aquatic habitat available at various low levels of river discharge. Existing water quality models will be used to indicate the effects of increased river discharge on water quality in Pool 2.

Information about the basic limnology of the headwaters lakes is needed to predict the effects of lower lake stages on habitat available for whitefish. Detailed lake bed bathymetry in selected areas will allow determination of water depth for boat access to docks, landings, connecting channels, and wild rice beds. A hydrologic analysis of the lake system must be conducted to determine the lowest acceptable lake levels that would allow the lakes to return to normal lake levels. This analysis will help determine the amount of water potentially available from the lakes.

The St. Paul District, Corps of Engineers is conducting a review of the low flow operation of the headwaters system. The information needs listed above will be filled to the extent practicable. More quantitative information about water use demands and availability of water for release will allow more informed decisions about operation of the headwaters system. Modification of the low flow release plan may ultimately occur as a result of this study.

**Alternative Water Supply Possibilities in the Minneapolis-St. Paul Metropolitan Area**

C. Edward Bowers, Department of Civil and Mineral Engineering, University of Minnesota, Minneapolis, MN (Professor Emeritus)

**Wells.** Additional wells in the metropolitan area appear to offer an excellent source of water, but serious consideration should be given to the following: (1) many suburban communities must depend only on the Jordan aquifer as a source of water; (2) wells should be used as a source of water for Minneapolis and St. Paul only in periods of low flow in the Mississippi River to reduce demand on the Jordan aquifer; (3) heavy use of wells by Minneapolis and St.Paul may result in groundwater contamination; (4) legislation should be introduced to prevent further use of groundwater for inefficient air conditioning systems, and to curtail use of existing systems.

The St. Croix River is an excellent potential source of water for the metropolitan area, especially during lowflow periods on the Mississippi River. It has received consideration in the past but further study of this option is needed. The Metropolitan Council should initiate such a study, with primary emphasis on use during drought periods.

**Headwaters Reservoirs.** The headwaters reservoirs of Winnibigoshish, Leech and Pokegema are an excellent potential source of water for the metropolitan area in periods of very low flow in the Mississippi River. At optimum summer levels, Winnibigoshish has a surface area of 106 square miles, Leech 184 square miles and Pokegema 13 square miles, or a total of 303 square miles. Sandy, Pine and Gull Lakes have been omitted as they have relatively small areas. A one-foot depth of water on these reservoirs would have a volume of 193,920 acre feet. If a one foot level were reserved for downstream use Winnibigoshish would constitute an excellent reserve.
To understand the volume of water in these lakes, consider the following: the average flow into the Minneapolis water system over a 12-year period is 63 mgd or 93 cfs. If the entire water supply for Minneapolis for a one-year period were withdrawn from the above three lakes, the water level would be lowered only 0.36 feet (4.3 inches). It is doubtful this would create serious problems for residents in the headwaters area.

The Corps of Engineers operates the headwater reservoirs in the best interests of all concerned. However, for the past 50 years the primary effort has been to maintain water levels in the lakes during the period May 1 to September 30. During this period, small releases are necessary for fish and wildlife.

Figure 22 shows an Elevation-Damage Graph for Leech Lake[1]. This shows damages that may result from lake levels other than the desired summer range of 1294.5 to 1294.9 ft. The damages are based on flood damage, erosion, changes in net income to commercial activities, harbor maintenance, reduced or cancelled reservations because of poor fishing, damaged equipment.

Figure 23 shows water levels in Leech Lake Reservoir, in accordance with the "Present Operating Plan" of the St. Paul District, Corps of Engineers. An attempt is made to maintain a "desirable summer range" in water levels of 1294.5 to 1294.0 feet from May 1 to September 30. The level is then drawn down from October 1 to January 31 in preparation for spring snowmelt. (Similar graphs are available for the other five reservoirs). Thus, there is an annual drawdown in water surface elevation for proper operation of the reservoirs. Small flows are usually released during summer to maintain a proper level and for fish and wildlife.

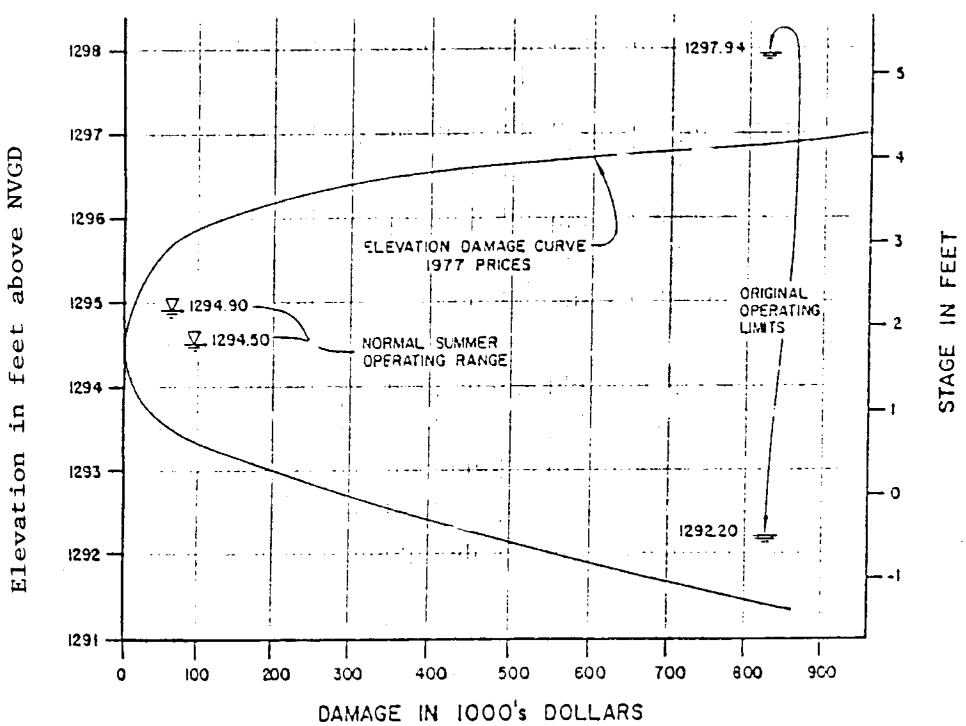


Figure 22. Elevation-Damage Graph for Leech Lake.

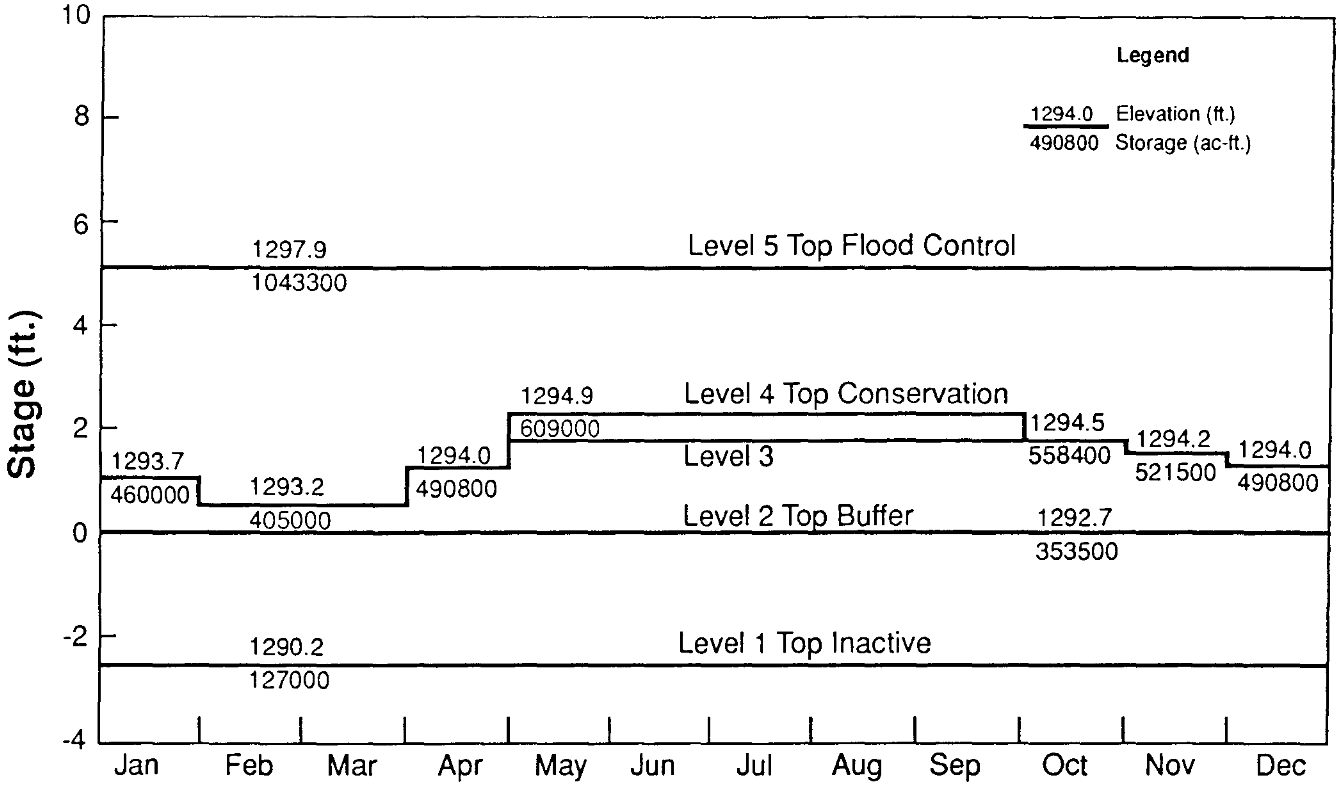


Figure 23. Schematic view of elevations for Leech Lake Reservoir according to present Corps of Engineers operating plan.

The Corps of Engineers has estimated that by the year 2015 the minimum flow of the Mississippi River near Anoka should be 1600 cfs; at present this minimum is about 1000 cfs. During the past 57 years the average monthly flow at this site has fallen below 1000 cfs in only five months, or less than 1% of the time. (Monthly average low flows are used here to avoid the daily oscillations associated with a nearby dam.) Thus, for 99 percent of the time it was not critical to provide releases for downstream use. Releases were still necessary for fish and wildlife and to provide a reasonable riparian flow.

Residents living around the reservoirs have been vocal in resisting releases for downstream use, although they have received primary consideration in operation of the dams. This is regrettable as there is an ample supply of water to maintain the levels of the reservoirs and for downstream use during very infrequent drought periods. It is hoped that discussions between upstream and downstream users will result in cooperation in the fair use of the Mississippi River system.

The Metropolitan Council, the Department of Natural Resources, and the communities making up the metropolitan area should take a more active role in generating support for an equitable plan for lowflow operation of the Mississippi River system in cooperation with the Corps of Engineers, upstream users and Legislators.

Reference:

[1] From "Computer Operations Study of Reservoir Operations for Six Mississippi River Headwaters Dams", June 1982. Prepared by Anderson-Nichols Col., Inc., Palo Alto, CA for the St. Paul District Corps of Engineers.

**City of New Brighton, A Case History**

Leslie J. Proper, P.E., Director of Public Works, New Brighton, MN

The Twin Cities metropolitan area is blessed with an abundant groundwater supply; the Twin Cities artesian basin. Expanded use of this groundwater supply should be considered in any future water contingency plan. Estimates from the Metropolitan Water Resources Management Plan[1] (1986) indicate that groundwater supply is three times greater than the anticipated future demand.

| Groundwater Use | 1980 | 1990 | 2000 |
|---|---|---|---|
| | 246 mgd | 308 mgd | 331 mgd |

| Estimated Aquifer Yield | |
|---|---|
| Prairie du Chien-Jordan | 885 mgd |
| Mount Simon-Hinckley | 220 mgd |
| Ironton-Galesville | 108 mgd |
| St. Peter | 95 mgd |
| Drift | 69 mgd |
| Total | 1,377 mgd |

It is noted that more recent estimates of groundwater availability in the metro region were given by the first panel and indicate sustainable yields may be only half as large as the above estimates. Nonetheless, even the lower values are greater than predicted demands.

The major threats to our groundwater supplies are contamination from chemical spills, leaking landfills, and underground tanks. The Minnesota Pollution Control Agency has identified 139 Superfund sites in the state, 59 of which are in the metro area, and 650 leaking underground storage tanks, over half of which are in the metro area. A very small amount of chemicals can contaminate a very large quantity of groundwater. Once in the groundwater, cleanup is very difficult and expensive. In one small outstate community, less than 15 pounds of trichloroethylene will cost an estimated $1 million to remove from a shallow drift aquifer.

Contamination of the Prairie du Chien-Jordan aquifer by the Twin Cities Army Ammunition plant is one of the most best known groundwater contamination cases in Minnesota. A case history follows.

In July of 1981, the City of New Brighton was notified by the Minnesota Department of Health that volatile organic chemicals were found in the city's water supply wells. Because of potential health risks, the Minnesota Department of Health directed New Brighton to replace the contaminated supply as soon as possible.

At the time the New Brighton water supply consisted of eight wells in the Prairie du Chien-Jordan aquifer with a combined pumping capacity of 8,250 gallons per minute, 2.6 million gallons of elevated storage and approximately 70 miles of distribution system. The water system serves a population of 23,500. The city had an average water demand of about 2.5 mgd and experienced peak demands of approximately 7.5 mgd when lawn watering was heavy.

The chemicals discovered in the New Brighton water supply were trichloroethylene, trichloroethane, and 1,1-dichloroethylene. Six of the city's eight wells were affected at levels ranging from 5 to 300 parts per billion (ppb). The regulatory level for the predominant chemical, trichloroethylene, was 27 ppb.

The suspected source of contamination was the Twin Cities Army Ammunition Plant (TCAAP) located just north and east of New Brighton. TCAAP initially denied responsibility for the contamination.

To replace the contaminated water supply, the city explored treatment of the existing supply, purchase of water from a neighboring city, and construction of new wells. Constructing new wells into the deeper Mount Simon-Hinckley aquifer was selected. By the summer of 1984, the city had completed construction of five new wells at a cost in excess of $4.7 million. The Mount Simon-Hinckley wells have a much lower yield than the old Prairie du Chien-Jordan wells and the city has had to control water demand peaks with stringent lawn watering restrictions. A comparison of a New Brighton Prairie du Chien-Jordan well and Mount Simon-Hinckley well is summarized below.

| | Prairie du Chien-Jordan | Mount Simon-Hinckley |
|---|---|---|
| Capacity | 1500 gpm | 800 gpm |
| Depth | 490 ft | 990 ft |
| Spec. yield | 100 gpm/ft | <10 gpm/ft |
| Static level | 170 ft | 390 ft |
| Pumping level | 185 ft | 470 ft |
| Treatment | none | iron removal |
| Pump length | 230 ft | 500 ft |
| Aquifer thickness | 200 ft | 200 ft |
| Available head | 100 ft | 400 ft |
| Well cost | $75,000 | $250,000 |
| Treatment cost | 0 | $750,000 |

In August of 1988, the city and TCAAP reached a settlement consisting of a cash payment to the city and the construction of a 4.0 mgd granular activated carbon (GAC) facility to treat water from four of the contaminated wells. The GAC facility will have the dual purpose of restoring the city's pumping capacity as well as beginning to clean up the aquifer. The TCAAP will pay the city to operate the GAC facility until the aquifer meets drinking water standards, which are currently 5 ppb for trichloroethylene. It is estimated that cleanup may take 25 to 50 years.

Reference

[1] Metropolitan Council. Water Resource Management Development Guide/Policy Plan. Part III. St. Paul, May, 1986.